FLORIDA SOLAR ENERGY CENTER®

CONTRACT REPORT

Expand the Modeling Capabilities of DOE's EnergyPlus™ Building Energy Simulation Program

Final Technical Report for
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submitted by:

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DISCLAIMER

EXECUTIVE SUMMARY

EnergyPlus™ is a new generation computer software analysis tool that has been developed, tested, and commercialized to support DOE's Building Technologies (BT) Program in terms of whole-building, component, and systems R&D (http://www.energyplus.gov). It is also being used to support evaluation and decision making of zero energy building (ZEB) energy efficiency and supply technologies during new building design and existing building retrofits. Version 1.0 of EnergyPlus was released in April 2001, followed by semiannual updated versions over the ensuing seven-year period.

This report summarizes work performed by the University of Central Florida's Florida Solar Energy Center (UCF/FSEC) to expand the modeling capabilities of EnergyPlus. The project tasks involved implementing, testing, and documenting the following new features or enhancement of existing features:

- A model for packaged terminal heat pumps
- A model for gas engine-driven heat pumps with waste heat recovery
- Proper modeling of window screens
- Integrating and streamlining EnergyPlus air flow modeling capabilities
- Comfort-based controls for cooling and heating systems
- An improved model for microturbine power generation with heat recovery

UCF/FSEC located existing mathematical models or generated new model for these features and incorporated them into EnergyPlus. The existing or new models were (re)written using Fortran 90/95 programming language and were integrated within EnergyPlus in accordance with the EnergyPlus Programming Standard and Module Developer's Guide. Each model/feature was thoroughly tested and identified errors were repaired. Upon completion of each model implementation, the existing EnergyPlus documentation (e.g., Input Output Reference and Engineering Document) was updated with information describing the new or enhanced feature. Reference data sets were generated for several of the features to aid program users in selecting proper model inputs. An example input data file, suitable for distribution to EnergyPlus users, was created for each new or improved feature to illustrate the input requirements for the model.

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1.0 INTRODUCTION

In April 2001 the U.S. Department of Energy released EnergyPlus^{TM} Version 1.0, a new computer software program for modeling heating, cooling, lighting, ventilating, water, and other energy flows in buildings (http://www.energyplus.gov). This program combines the best capabilities and features of its parent programs (DOE-2.1E and BLAST) along with new capabilities and flexibility. EnergyPlus has innovative simulation capabilities, including simulation time steps of less than one hour, modular systems modules that are integrated with a heat balance-based zone simulation, and input and output data structures tailored to facilitate third-party interface development. The integrated systems modules/heat balance solution technique allows for evaluation of interactions between various building components and subsystems, a key deficiency in the earlier programs, but absolutely necessary to enable whole-building optimization.

When EnergyPlus Version 1.0 was released, it had many unique simulation capabilities to foster the design of high-performance buildings. While the program's modeling capabilities steadily increased over the ensuing years, additional key new features or enhancements to existing features were still needed to further support research, design and analysis of high performance and zero-energy buildings. These key features were:

- A model for packaged terminal heat pumps
- A model for gas engine-driven heat pumps with waste heat recovery
- Proper modeling of window screens
- Integrating and streamlining EnergyPlus air flow modeling capabilities
- Comfort-based controls for cooling and heating systems
- An improved model for microturbine power generation with heat recovery

Through this DOE-sponsored project, the University of Central Florida's Florida Solar Energy Center (UCF/FSEC) added these modeling features to EnergyPlus. As each new or enhanced feature was implemented it was included in the next version of the simulation program, and all of the new/enhanced features were included in EnergyPlus Version 2.2, released in April 2008. This report summarizes the models selected for implementation, the model testing that was performed, and the documentation that was developed for program users to understand the model inputs, outputs and modeling methodology.

2.0 SUMMARY OF IMPLEMENTED MODELING FEATURES

This section briefly describes the new models or enhancements to existing models that were implemented in EnergyPlus as part of this project.

Task 1 – Packaged Terminal Heat Pump Model

Packaged terminal air conditioners and heat pumps are self-contained cooling and heating systems that are primarily intended to condition a single zone without the use of additional air distribution ductwork. These units are produced for a wide range of residential and commercial building applications, including hotels, motels, offices, apartments, dormitories and nursing homes. Minimum energy efficiency levels for these units are established by various codes and standards, including ASHRAE Standard 90.1 and California's Title 24 Building Energy Efficiency Standards. In addition, electric utilities companies sometimes provide financial incentives to install high-efficiency models to encourage peak demand reductions and energy savings.

EnergyPlus already contained a model for window air conditioners that could also be used to model packaged terminal air conditioners. However, that existing model was unable to model heat pump operation to provide space heating. In 2001, UCF/FSEC added a multizone air-to-air heat pump model to EnergyPlus based, in part, on a model contained in DOE-2.1E. However, the multizone heat pump model requires an entire air distribution system to be specified, which is cumbersome and time consuming if the user only needs to model a heat pump cooling and heating system for a single zone within the building.

Given the existing program limitations, UCF/FSEC added the capability to model single-zone packaged terminal heat pumps (PTHPs) in EnergyPlus by combining the program's existing model for window air conditioners and the heating algorithms (heat pump heating operation, coil defrosting and supplemental heater operation) from the existing multizone air-to-air heat pump model. The resulting new EnergyPlus input object is named PackagedTerminal:HeatPump: AirToAir. Once the model implementation was completed, the simulation results with the new model were compared to those produced with the existing multizone air-to-air heat pump model configured to serve a single thermal zone. As expected, there was excellent agreement between the simulation results produced with the new model and those with the existing model.

Task 2 – Gas Engine-Driven Heat Pumps with Waste Heat Recovery

As explained previously, UCF/FSEC added a multizone air-to-air heat pump model to EnergyPlus in 2001. The existing model assumed a conventional configuration where the compressor is driven by an electric motor. However, a natural gas combustion engine can be used in place of the compressor's electric motor. High efficiency, engine-driven heating and cooling systems can provide significant operating cost savings compared to conventional equipment, although savings are dependent on local energy prices. These systems are typically over 30% more efficient than even the highest efficiency gas furnaces. Furthermore, energy efficiency can be further increased and operating costs decreased by reclaiming waste energy to heat water.

The initial strategy for this project task was to implement the existing air-cooled, engine-driven heat pump model from the DOE-2.1E building energy simulation program in EnergyPlus. However, several insurmountable issues arose during implementation of that existing model, including uncertainty regarding the calculations for sensible/latent capacity split, power input, and waste heat recovery. Therefore UCF/FSEC, the EnergyPlus development team, and DOE/NETL agreed on a revised strategy. The revised plan involved developing and implementing a multi-speed air-to-air heat pump model instead of implementing the existing variable-speed heat pump model from DOE-2.1E. The multi-speed heat pump model would be more flexible for EnergyPlus users, and would also be better suited to assist Oak Ridge National Laboratory (ORNL) with their product development project with a manufacturing partner. In addition, ORNL was willing to perform detailed equipment testing and provide measured data to UCF/FSEC for model validation (model validation with measured data was performed under a separate DOE award, DE-FC26-06NT42768).

The multi-speed air-to-air heat pump model developed under this project was largely based on existing EnergyPlus models for single-speed heat pumps and two-speed direct expansion (DX) cooling coils. A multi-speed DX heating coil model was developed based on the existing EnergyPlus model for a single-speed DX heating coil. The new multi-speed heat pump model is quite flexible, allowing between two and four stages of cooling and heating with different supply air flow rates for each stage and operating mode (cooling/heating). The user can also specify fuel input type (e.g., natural gas or electricity). Furthermore, the model allows waste energy recovery to heat water. Once the new model was completed, the simulation results with the new model were compared to those produced with the existing EnergyPlus heat pump/coil models for scenarios that could be simulated by both. Subsequently, model validation was performed under a separate DOE award using measured laboratory performance data and good agreement was found (no model changes were required, but a couple of logic statement errors were corrected as a result of this model validation effort).

Task 3 – Proper Modeling of Window Screens

Proper modeling of window heat gains is vitally important when evaluating building energy usage, particularly high performance and zero-energy buildings where extensive building envelope improvements are employed to minimize cooling and heating equipment requirements. EnergyPlus already contained models for numerous simple and complex window systems, exterior shades, window blinds, etc. One notable deficiency, however, was the inability to properly model exterior window screens. EnergyPlus could only model screens as planar surfaces having a fixed transmittance, which was correct only when the sun is perpendicular to the window.

Therefore, UCF/FSEC developed and implemented modeling algorithms in EnergyPlus to improve the program's ability to model the angle-dependent solar transmittance of exterior window screens. This task included a literature review to identify previous studies of this issue and acquisition of materials and design information from screen manufacturers. Analytical formulations were developed and optical ray tracing simulations was performed to verify and refine the analytical model. The initial model assumed that the screen material fully absorbed any incident solar radiation, but further enhancements accounted for the impact of reflection and scattering of solar flux by the screen material. The resulting model was then incorporated into EnergyPlus, along with reference input data sets for five typical screen materials and appropriate documentation to provide guidance for model usage. The model also produces a file (eplusscreen.csv) which contains values for direct beam and reflected beam transmittance through the screen as a function of the relative azimuth and altitude angles of the sun with respect to the screen.

Task 4 – Integrating and Streamlining EnergyPlus Air Flow Modeling Capabilities

This task was originally titled “Air distribution system model for variable-air-volume systems”. However the task scope was modified via contract amendment in June 2005. The modified task involved completing the testing and documentation of an integrated air flow model within EnergyPlus. Specifically, UCF/FSEC completed an integrated air flow model in mid-December 2005 through other DOE funding. Under this DOE/NETL project, UCF/FSEC completed rigorous model testing, modified the preliminary implementation as necessary based on test results, completed extensive user and engineering documentation, and developed sample input data files to assist users. In addition, UCF/FSEC added the capability to model individual control of large openings in surfaces (e.g., a window in an exterior wall) to complement the existing zone-level opening controls that were included in the original model implementation.

Task 5 – Comfort-Based Controls for Cooling and Heating Systems

Cooling and heating systems are typically controlled to keep the indoor dry-bulb temperature from exceeding certain levels (set points). In some cases, indoor humidity levels are also actively controlled within a certain range (e.g., supermarkets, museums, cleanrooms). Thermal comfort, however, depends on several factors, including temperature, humidity, air velocity, clothing level, metabolic rate and radiant heat exchange. The performance of certain systems may benefit by controlling to achieve a constant level of occupant comfort rather than a constant dry-bulb temperature. For example, EnergyPlus can be used to evaluate the costs and benefits of radiant heating systems controlled to maintain either dry-bulb, mean radiant or operative temperature.

As part of this project UCF/FSEC extended this “comfort control” concept to forced-air systems in EnergyPlus. For example, users are now able to evaluate advanced dehumidification systems for buildings located in hot-humid climates where lower indoor humidity levels could allow for higher indoor temperatures without sacrificing occupant comfort. Under this task, UCF/FSEC evaluated existing EnergyPlus thermal comfort models and determine their feasibility for comfort control of forced-air systems. One of the existing thermal comfort models (i.e., Fanger Predicted Mean Vote [PMV]) was deemed appropriate for this new “comfort control” feature. The new control feature allows the user to define a single “comfort” setpoint (for cooling, heating, or both) or dual independent setpoints for cooling and heating. UCF/FSEC developed appropriate user and engineering documentation consistent with EnergyPlus guidelines, and also developed a sample input data file to help program users understand model usage.

Task 6 – Microturbine Power Generation with Heat Recovery

On-site power generation by small-scale combined heat/power equipment is one of several promising options being actively developed and evaluated by DOE as part of its zero-energy building concept. For example, DOE recently spent in excess of $60 million under its Advanced Microturbine Program to increase the efficiency, durability and fuel flexibility of microturbines while reducing emissions and system costs (http://www.eere.energy.gov/de/microturbines/).

EnergyPlus already included a combustion turbine generator model derived from BLAST, a predecessor building energy simulation program. However, analysis by UCF/FSEC indicated that this existing model does not allow proper performance modeling of currently-available microturbine systems with optional waste heat recovery. Therefore, UCF/FSEC obtained performance information from several microturbine manufacturers and develop appropriate models for their performance. Instead of updating the existing EnergyPlus combustion turbine generator model, there were sufficient differences to justify adding an entirely new, separate model to EnergyPlus. The new model (input object name = Generator:Microturbine) was thoroughly tested in terms of electric power production, fuel consumption and waste heat recovery by comparing model results with the manufacturer's performance data. EnergyPlus' user/engineering documentation was updated to describe the new model. Reference input data sets were created based on manufacturer's data which will aid the user in quickly selecting and evaluating various systems.

3.0 RESULTS AND DISCUSSION

Each new or enhanced feature summarized in Section 2.0 was implemented in EnergyPlus, with the order of implementation determined in consultation with NETL, the DOE Headquarters Technology Development Officer, and other members of the EnergyPlus development team. Table 1 below summarizes the completion date for each task and the version of EnergyPlus that included the new or enhanced feature.

Table 1. New or Enhanced Feature Implementation Schedule

Task Description	**Date Completed**	**EnergyPlus Version[1]**
Task 1: Packaged Terminal Heat Pump Model	Sept 2005	1.2.3
Task 2: Gas Engine-Driven Heat Pumps with Waste Heat Recovery	Aug 2007	2.1
Task 3: Proper Modeling of Window Screens	June 2006	1.4
Task 4: Integrating and Streamlining EnergyPlus Air Flow Modeling Capabilities	Mar 2006	1.3
Task 5: Comfort-Based Controls for Cooling and Heating Systems	June 2006	1.4
Task 6: Microturbine Power Generation with Heat Recovery	Feb 2008	2.2

Note: [1]Version of EnergyPlus that included this new or enhanced feature.

As explained previously, UCF/FSEC located existing mathematical models or generated new models for these features. The models selected for implementation were described previously in Section 2.0 of this report. The existing or new models were (re)written using Fortran 90/95 programming language and were integrated within EnergyPlus in accordance with the EnergyPlus Programming Standard and Module Developer's Guide. Each model/feature was thoroughly tested and identified errors were repaired (model testing is described in Section 2.0 of this report). Per contract requirements, the computer source code was delivered in electronic form to DOE's official repository for all EnergyPlus-related information (StarTeam).

EnergyPlus user documentation includes an Input Output Reference and an Engineering Reference. The Input Output Reference provides users with a brief description of each simulation model and fully describes the data input requirements, as well as the output variables available for reporting the simulation results. The Engineering Reference gives a complete model description including key mathematical equations and a description of how associated controls are modeled. After completing source code development and testing for each new or enhanced feature, appropriate user documentation was developed to describe the feature which was suitable for inclusion in the 'master' EnergyPlus software documentation. The new and/or revised documentation sections were completed prior to the release of the EnergyPlus version that included each new or enhanced feature. The user documentation sections that were developed and/or revised under this contract are provided in Appendices A through F of this report.

One or more example input data files, suitable for distribution to EnergyPlus users, were created (or existing example files were revised) for each new or improved feature to illustrate the input requirements for the model. For Task 3 (Window Screens) and Task 5 (Microturbine Power Generation), reference data sets were also generated to aid program users in selecting proper inputs for these models (these reference data sets are included in Appendix C and Appendix F of this report). Both the example input files and reference data sets were delivered in electronic form to DOE's official repository for all EnergyPlus-related information (StarTeam), and were subsequently distributed to EnergyPlus users beginning with the version that included each new or improved feature. Table 2 summarizes the example input data files and reference data set files that were generated for each feature.

Table 2. Example Input Data File and Reference Data Set File Summary

Task Description	Example Input Data Files	Reference Data Set Files
Task 1: Packaged Terminal Heat Pump Model	PackagedTerminalHeatPump.idf	NA
Task 2: Gas Engine-Driven Heat Pumps with Waste Heat Recovery	MultiSpeedHeatPump.idf	NA
Task 3: Proper Modeling of Window Screens	WindowTests.idf	WindowScreenMaterials.idf
Task 4: Integrating and Streamlining EnergyPlus Air Flow Modeling Capabilities	AirflowNetwork3zVent.idf AirflowNetwork3zVentAutoWPC.idf AirflowNetwork_MultiZone_House.idf AirflowNetwork_MultiZone_SmallOffice.idf AirflowNetwork_Simple_House.idf AirflowNetwork_Simple_SmallOffice.idf	NA
Task 5: Comfort-Based Controls for Cooling and Heating Systems	FurnaceWithDXSystemComfortControl.idf	NA
Task 6: Microturbine Power Generation with Heat Recovery	Generators.idf HeatRecoveryPlantLoop.idf	ElectricGenerators.idf

NA – not applicable

4.0 CONCLUSION

EnergyPlus™ is a new generation computer software analysis tool that has been developed, tested, and commercialized to support DOE's Building Technologies (BT) Program in terms of whole-building, component, and systems R&D (http://www.energyplus.gov). It is also being used to support evaluation and decision making of zero energy building (ZEB) energy efficiency and supply technologies during new building design and existing building retrofits. Version 1.0 of EnergyPlus was released in April 2001, followed by semiannual updated versions over the ensuing seven-year period.

Six new or enhanced modeling features were added to EnergyPlus during this project. Several of the new features (e.g., packaged terminal heat pumps and gas engine-driven heat pumps) were implemented to help meet one of DOE's near-term goals of completing the incorporation of current technologies, systems, and controls into EnergyPlus to support energy codes and standards. Energy standards, such as ASHRAE Standard 90.1, ASHRAE Standard 90.2, California Title 24, and the Florida Energy Code were developed with whole-building simulation tools and future improvements to these standards cannot be developed without analysis tools. New and currently-available technologies cannot be considered in a standard unless the tool used to produce the standard can properly model that technology.

The other new or enhanced modeling features were added to support low energy building design (i.e., air flow modeling, window screens, comfort-based controls, and microturbine power generators with heat recovery). With the aggressive energy efficiency goals set by DOE, large improvements in building envelope design, equipment controls, utilization of natural ventilation, and high-efficiency on-site power generation will need to be assessed and implemented. The work completed under this contract significantly enhances EnergyPlus' ability to evaluate various options which can contribute toward achieving high performance, low energy buildings.

Appendix A

EnergyPlus Documentation for the Packaged Terminal Heat Pump Model

This appendix contains the EnergyPlus documentation (Input/Output Reference and Engineering Manual sections) for the packaged terminal heat pump model that was added as part of this project.

Input Output Reference for PackagedTerminal:HeatPump:AirToAir

The packaged terminal heat pump (PTHP) is a compound object made up of other components. Each PTHP consists of an outside air mixer, direct expansion (DX) cooling coil, DX heating coil, supply air fan, and a supplemental heating coil as shown in the figure below. These individual components are described elsewhere in this document. The packaged terminal heat pump coordinates the operation of these components and is modeled as a type of zone equipment (Ref. Zone Equipment List and Controlled Zone Equip Configuration).

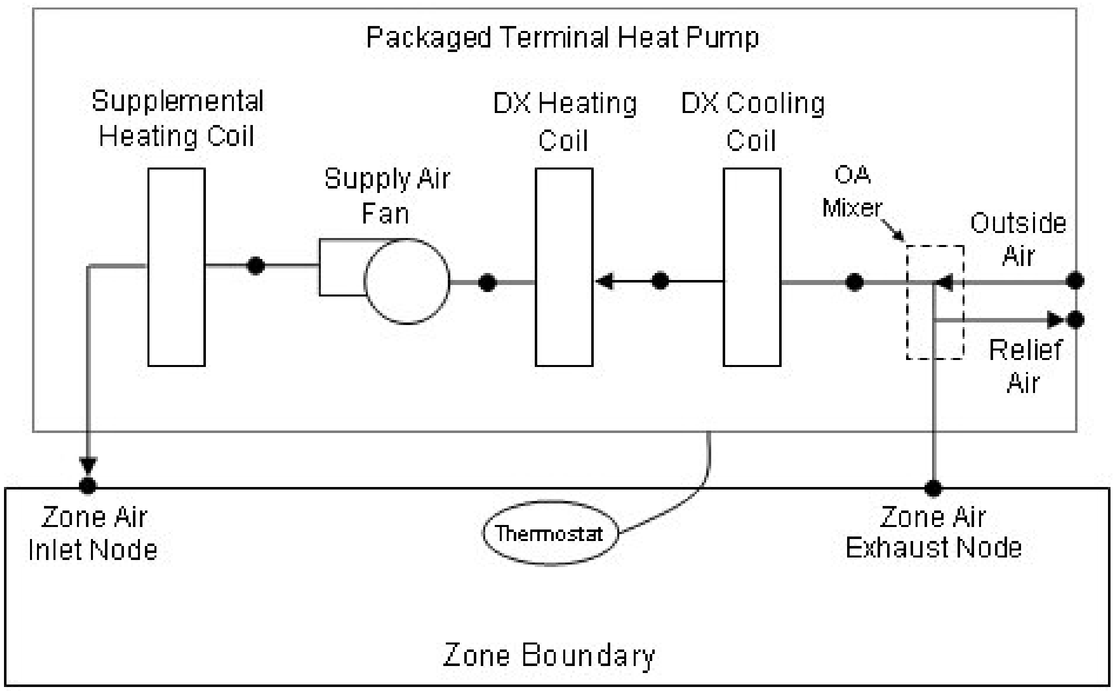


Figure 1. Schematic of a packaged terminal heat pump (draw through fan placement)

Links to the PTHP's supply air fan, DX coils, supplemental heating coil, and outside air mixer specifications are provided in the heat pump's input syntax. Additional inputs include supply and outside air flow rates during cooling operation, heating operation, and when neither cooling or heating is required. A description of each input field for the packaged terminal heat pump compound object is provided below.

Field: Heat pump name

This alpha field defines a unique user-assigned name for an instance of a packaged terminal heat pump. Any reference to this heat pump by another object will use this name.

Field: Availability schedule name

This alpha field defines the name of the schedule (ref: Schedule) that denotes whether the heat pump operates during a given time period. A schedule value equal to 0 denotes that the heat pump must be off for that time period. A value greater than 0 denotes that the heat pump is available to operate during that time period. This schedule may be used to completely disable the heat pump (all of its coils and the supply air fan) as required.

Field: Air inlet node name

This alpha field defines the name of the HVAC system node from which the heat pump draws its inlet air. This node name must be the name of a zone air exhaust node (Ref. Controlled Zone Equip Configuration).

Field: Air outlet node name

This alpha field defines the name of the HVAC system node to which the heat pump sends its outlet air. This node name must be the name of a zone air inlet node (Ref. Controlled Zone Equip Configuration).

Field: Outside air mixer name

This alpha field defines the name of an outside air mixer component which composes part of the PTHP. Note that the return air node of the outside air mixer should also be the same node as the air inlet node of the PTHP. Furthermore, the outside air mixer's mixed air node should be the same as the PTHP's fan inlet air node (for blow through fan placement) or the PTHP's DX cooling coil inlet node (for draw through fan placement).

Field: Supply air volumetric flow rate during cooling operation

This numeric field defines the supply air flow rate leaving the heat pump in cubic meters per second when the DX cooling coil is operating. Values must be greater than 0 or this field is autosizable.

Field: Supply air volumetric flow rate during heating operation

This numeric field defines the supply air flow rate leaving the heat pump in cubic meters per second when the DX heating coil and/or supplemental heater are operating. Values must be greater than 0 or this field is autosizable.

Field: Supply air volumetric flow rate when no cooling or heating is needed

This numeric field defines the supply air flow rate leaving the heat pump in cubic meters per second when neither cooling nor heating is required (i.e., DX coils and supplemental heater are off but the supply air fan operates). This field is only used when the heat pump's supply air fan operating mode schedule specifies continuous fan operation. Values must be greater than or equal to zero, or this field is autosizable. If the heat pump's supply air fan operating mode schedule specifies continuous fan operation and this value is set to zero or this field is left blank, then the model assumes that the supply air flow rate when no cooling/heating is needed is equal to the supply air flow rate when the cooling or heating coil was last operating (for cooling operation or heating operation).

Field: Outside air volumetric flow rate during cooling operation

This numeric field defines the outdoor air flow rate through the heat pump in cubic meters per second when the DX cooling coil is operating. Values must be greater than or equal to 0, or this field is autosizable. Note that the outside air flow rate during cooling operation is fixed; it cannot change during the simulation. In addition, the outside air flow rate during cooling operation cannot be greater than the heat pump's supply air volumetric flow rate during cooling operation.

Field: Outside air volumetric flow rate during heating operation

This numeric field defines the outdoor air flow rate through the heat pump in cubic meters per second when the DX heating coil and/or supplemental heater are operating. Values must be greater than or equal to 0, or this field is autosizable. Note that the outside air flow rate during heating operation is fixed; it cannot change during the simulation. In addition, the outside air flow rate during heating operation cannot be greater than the heat pump's supply air volumetric flow rate during heating operation.

Field: Outside air volumetric flow rate when no cooling or heating is needed

This numeric field defines the outdoor air flow rate through the heat pump in cubic meters per second when neither cooling nor heating is required (i.e., DX coils and supplemental heater are off but the supply air fan operates). Values must be greater than or equal to 0, or this field is autosizable. Note that the outside air flow rate when no cooling/heating is needed is fixed; it cannot change during the simulation. In addition, the outside air flow rate when no cooling/heating is needed cannot be greater than the heat pump's supply air volumetric flow rate when no cooling/heating is needed. This field is only used when the heat pump's supply air fan operating mode schedule specifies continuous fan operation. If the heat pump's supply air fan operating mode schedule specifies continuous fan operation and the field 'Supply air volumetric flow rate when no cooling or heating is needed' is set to zero or is left blank, then the model assumes that the outside air flow rate when no cooling/heating is needed is equal to the outside air flow rate when the cooling or heating coil was last operating (for cooling operation [i.e., Outside air volumetric flow rate during cooling operation] or heating operation [i.e., Outside air volumetric flow rate during heating operation]) and this field is not used.

Field: Supply air fan type

This alpha field defines the type of fan used by this PTHP. The only valid choices are Fan:Simple:OnOff and Fan:Simple:ConstVolume. A fan of type Fan:Simple:OnOff may be used with either cycling or continuous fan operating mode, and a fan of type Fan:Simple:ConstVolume is used only with continuous fan operating mode (see Supply Air Fan Operating Mode Schedule field below). The input requirements for these fan objects are described elsewhere in this document.

Field: Supply air fan name

The name of a constant volume fan component that composes part of the PTHP. Note that the fan's maximum flow rate should be greater than or equal to the maximum supply air flow rate for the PTHP. The fan's inlet node should be the same as the outside air mixer's mixed air node (for blow through fan placement) or the DX heating coil's outlet node (for draw through fan placement). The fan's outlet node should be the same as the DX cooling coil's air inlet node (for blow through fan placement) or the supplemental heater's air inlet node (for draw through fan placement).

Field: Heating coil type

This alpha field defines the type of DX heating coil to be used by this PTHP. The only valid choice is Coil:DX:HeatingEmpirical. The input requirements for this DX heating coil object are described elsewhere in this document.

Field: Heating coil name

This alpha field defines the name of the DX heating coil used by this PTHP, and this name should match the name specified in the corresponding DX heating coil object.

Field: Heating convergence tolerance

This numeric field defines the convergence tolerance for the unit's heating output. This field allows the user some control over how closely the heat pump will control the air-side conditions. The relative size of this parameter relates directly to the closeness of the control. A very small value in this field will result in tight control and will probably result in larger numbers of iterations. A large value in this field will result in looser controls and could result in unsatisfactory fluctuations in zone air temperature. Initial experience with this parameter lends to the recommendation of using 0.001 as the starting point.

The heat pump is controlled by matching its sensible (temperature) heating output to the zone sensible load (demand). Because the performance of the DX heating coil is frequently non-linear, the heat pump model must call the DX heating coil model several times (iterate) to determine the proper run time fraction to meet the zone load. The heating convergence tolerance is the error tolerance used to terminate the iteration procedure when the following equation is satisfied:

$$\frac{\left|(Q_{ZoneLoad} - Q_{HeatPump,out})\right|}{Q_{ZoneLoad}} \leq HeatingConvergenceTolerance$$

The maximum number of iterations is limited, with a warning message generated if the above equation is not satisfied within the maximum number of iterations.

Field: Minimum outdoor dry-bulb temperature for compressor operation

This numeric field defines the minimum outdoor dry-bulb temperature in degrees Celsius for PTHP compressor operation. The compressor will not operate (for DX heating or DX cooling) when outdoor dry-bulb temperatures fall below this value. The minimum value must be greater than or equal to -20 °C. If this field is left blank, the default value is -8°C. This temperature should match the minimum compressor operating temperature specified for the heat pump's DX heating coil (if they don't match, the highest of the two temperatures will be the cut-off temperature for compressor operation).

Field: Cooling coil type

This alpha field defines the type of DX cooling coil used by this PTHP. There are two valid choices for this field: Coil:DX:CoolingBypassFactorEmpirical and Coil:DX:CoolingHeat ExchangerAssisted. The input requirements for these DX cooling coil objects are described elsewhere in this document.

Field: Cooling coil name

This alpha field defines the name of the cooling coil used by this PTHP, and this name should match the name specified in the corresponding DX cooling coil object.

Field: Cooling convergence tolerance

This numeric field defines the convergence tolerance for the unit's cooling output. This field allows the user some control over how closely the heat pump will control the air-side conditions. The relative size of this parameter relates directly to the closeness of the control. A very small value in this field will result in tight control and will probably result in larger numbers of iterations. A large value in this field will result in looser controls and could result in unsatisfactory fluctuations in zone air temperature. Initial experience with this parameter lends to the recommendation of using 0.001 as the starting point.

The heat pump is controlled by matching its sensible (temperature) cooling output to the zone sensible load (demand). Because the performance of the DX cooling coil is frequently non-linear, the heat pump model must call the DX cooling coil model several times (iterate) to determine the proper run time fraction to meet the zone load. The cooling convergence tolerance is the error tolerance used to terminate the iteration procedure when the following equation is satisfied:

$$\frac{\left|(Q_{ZoneLoad} - Q_{HeatPump,out})\right|}{Q_{ZoneLoad}} \le CoolingConvergenceTolerance$$

The maximum number of iterations is limited, with a warning message generated if the above equation is not satisfied within the maximum number of iterations.

Field: Supplemental heating coil type

This alpha field defines the type of supplemental heating coil to be used by this PTHP. There are two valid choices: Coil:Electric:Heating and Coil:Gas:Heating. The input requirements for these heating coil objects are described elsewhere in this document.

Field: Supplemental heating coil name

This alpha field defines the name of the supplemental heating coil used by this PTHP, and this name should match the name specified in the corresponding heating coil object.

Field: Maximum supply air temperature from supplemental heater

This numeric field defines the maximum supply air temperature in degrees Celsius exiting the heat pump supplemental heater coil. The supplemental heater will be controlled so that its supply air temperature does not exceed this value. This field is autosizable.

Field: Maximum outdoor dry-bulb temperature for supplemental heater operation

This numeric field defines the maximum outdoor dry-bulb temperature in degrees Celsius for PTHP supplemental heater operation. The supplemental heater will not operate when the outdoor dry-bulb temperature is above this value. The maximum value must be less than or equal to 21°C. If this field is left blank, the default value is 21°C.

Field: Fan placement

This alpha field has two choices: blow through or draw through. The first choice stands for “blow through fan”. This means that the unit consists of an outside air mixer followed by a fan followed by the DX coils and supplemental heating coil. The fan “blows through” the cooling and heating coils. The second choice stands for “draw through fan”. This means that the unit consists of an outside air mixer followed by the DX coil(s) followed by a fan, with the supplemental heater located at the outlet of the fan. The fan “draws air through” the DX coil(s). If this field is left blank, the default is draw through.

> Note: the packaged terminal heat pump’s supply air fan, cooling coil, heating coil and supplementary heating coil must be connected according to the configuration shown above (Figure 1) for the draw through fan configuration. The only other valid configuration is with a blow through fan placement, where the fan is located between the outside air mixer and the DX cooling coil.

Field: Supply Air Fan Operating Mode Schedule Name

This alpha field specifies the name of the supply air fan operating mode schedule. The supply air fan operating mode may vary during the simulation based on time-of-day or with a change of season. Schedule values of 0 denote that the supply air fan and the heating or cooling coil cycle on and off together to meet the heating or cooling load (a.k.a. AUTO fan). Schedule values other than 0 denote that the supply air fan runs continuously while the heating or cooling coil cycles to meet the load. If this field is left blank, the model assumes the supply air fan cycles with the heating or cooling coil throughout the simulation. The operating mode specified here overrides the operating mode specified in the cooling and heating coil objects.

Below is the IDD specification for the packaged terminal heat pump compound object.

```
PACKAGEDTERMINAL:HEATPUMP:AIRTOAIR,
        \min-fields 26
   A1,  \field Heat pump name
        \required-field
        \type alpha
        \note Unique name for this packaged terminal heat pump object.
   A2,  \field Availability schedule name
        \required-field
        \type object-list
        \object-list ScheduleNames
        \note Schedule values of 0 denote the unit is off.
   A3 , \field Air inlet node name
        \required-field
        \type alpha
        \note Air inlet node for the PTHP must be a zone air exhaust node.
   A4 , \field Air outlet node name
        \required-field
        \type alpha
        \note Air outlet node for the PTHP must be a zone air inlet node.
   A5 , \field Outside air mixer name
        \required-field
        \type alpha
        \note Needs to match name of outside air mixer object.
   N1 , \field Supply air volumetric flow rate during cooling operation
        \required-field
        \type real
        \units m3/s
        \minimum> 0.0
        \autosizable
        \note Must be less than or equal to fan size.
   N2 , \field Supply air volumetric flow rate during heating operation
        \required-field
        \type real
        \units m3/s
        \minimum> 0.0
        \autosizable
        \note Must be less than or equal to fan size.
   N3 , \field Supply air volumetric flow rate when no cooling or heating is needed
        \type real
        \units m3/s
        \minimum 0
        \autosizable
        \note Must be less than or equal to fan size.
        \note Only used when heat pump fan operating mode is ContFanCycComp. This air flow rate
        \note is used when no heating or cooling is required and the DX coil compressor is off.
        \note If this field is left blank or zero, the supply air flow rate from the previous on cycle
        \note (either cooling or heating) is used.
   N4 , \field Outside air volumetric flow rate during cooling operation
        \required-field
        \type real
        \units m3/s
        \minimum 0
        \autosizable
        \note Must be less than or equal to supply air volumetric flow rate during cooling operation.
   N5 , \field Outside air volumetric flow rate during heating operation
        \required-field
        \type real
        \units m3/s
        \minimum 0
        \autosizable
        \note Must be less than or equal to supply air volumetric flow rate during heating operation.
   N6 , \field Outside air volumetric flow rate when no cooling or heating is needed
        \type real
        \units m3/s
        \minimum 0
        \autosizable
        \note Only used when heat pump fan operating mode is ContFanCycComp. This air flow rate
        \note is used when no heating or cooling is required and the DX coil compressor is off.
        \note If this field is left blank or zero, the outdoor air flow rate from the previous on cycle
        \note (either cooling or heating) is used.
   A6 , \field Supply air fan type
        \required-field
        \type choice
        \key FAN:SIMPLE:ONOFF
```

```
       \key FAN:SIMPLE:CONSTVOLUME
       \note FAN:SIMPLE:CONSTVOLUME only works with operating mode = ContFanCycComp.
  A7 , \field Supply air fan name
       \required-field
       \type object-list
       \object-list FansCVandOnOff
       \note Needs to match in the fan object.
  A8 , \field Heating coil type
       \required-field
       \type choice
       \key COIL:DX:HeatingEmpirical
       \note Only works with Coil:DX:HeatingEmpirical.
  A9 , \field Heating coil name
       \required-field
       \type object-list
       \object-list HeatingCoilsDXSingleSpeed
       \note Needs to match in the DX heating coil object.
  N7 , \field Heating convergence tolerance
       \type real
       \minimum> 0.0
       \Default 0.001
       \units dimensionless
       \note Defines heating convergence tolerence as a fraction of the heating load to be met.
  N8 , \field Minimum outdoor dry-bulb temperature for compressor operation
       \type real
       \Minimum -20.0
       \Default -8.0
       \units C
       \note Needs to match the corresponding minimum outdoor temperature defined
       \note in the DX heating coil object.
  A10, \field Cooling coil type
       \required-field
       \type choice
       \key COIL:DX:CoolingBypassFactorEmpirical
       \key COIL:DX:CoolingHeatExchangerAssisted
       \note Only works with Coil:DX:CoolingBypassFactorEmpirical or
       \note Coil:DX:CoolingHeatExchangerAssisted.
  A11, \field Cooling coil name
       \required-field
       \type object-list
       \object-list CoolingCoilsDXSingleSpeed
       \note Needs to match in the DX cooling coil object.
  N9 , \field Cooling convergence tolerance
       \type real
       \minimum> 0.0
       \Default 0.001
       \units dimensionless
       \note Defines cooling convergence tolerence as a fraction of the cooling load to be met.
  A12, \field Supplemental heating coil type
       \required-field
       \type choice
       \key COIL:GAS:HEATING
       \key COIL:ELECTRIC:HEATING
       \note Only works with Coil:Gas:Heating or Coil:Electric:Heating.
  A13, \field Supplemental heating coil name
       \required-field
       \type object-list
       \object-list HeatingCoilsGasElec
       \note Needs to match in the supplemental heating coil object.
  N10, \field Maximum supply air temperature from supplemental heater
       \required-field
       \type real
       \units C
       \autosizable
       \note Supply air temperature from the supplemental heater will not exceed this value.
  N11, \field Maximum outdoor dry-bulb temperature for supplemental heater operation
       \type real
       \Maximum 21.0
       \Default 21.0
       \units C
       \note Supplemental heater will not operate when outdoor temperature exceeds this value.
  A14, \field Fan placement
       \type choice
       \key blow through
```

```
       \key draw through
       \Default draw through
       \note Select fan placement as either blow through or draw through.
  A15; \field Supply air fan operating mode schedule name
       \type object-list
       \object-list ScheduleNames
       \note Enter the name of a schedule that controls fan operation. Schedule values of 0 denote
       \note cycling fan operation (fan cycles with cooling or heating coil). Schedule values greater
       \note than 0 denote constant fan operation (fan runs continually regardless of coil operation).
       \note The fan operating mode defaults to cycling fan operation if this field is left blank.
```

As shown in the example below, correct specification of the packaged terminal heat pump requires the following objects in addition to the PACKAGEDTERMINAL:HEATPUMP: AIRTOAIR compound object itself:

1. Fan (FAN:SIMPLE:ONOFF or FAN:SIMPLE:CONSTVOLUME)
2. DX cooling coil (COIL:DX:CoolingBypassFactorEmpirical or COIL:DX:CoolingHeat ExchangerAssisted)
3. DX heating coil (Coil:DX:HeatingEmpirical)
4. Supplemental heating coil (COIL:GAS:HEATING or COIL:ELECTRIC:HEATING)
5. OUTSIDE AIR MIXER

```
PACKAGEDTERMINAL:HEATPUMP:AIRTOAIR,
    Zone2PTHP,                !- Heat pump name
    FanAndCoilAvailSched,     !- Availability schedule name
    Zone2PTHPAirInletNode,    !- Air inlet node name
    Zone2PTHPAirOutletNode,   !- Air outlet node name
    Zone2PTHPOAMixer,         !- Outside air mixer name
    autosize,              !- Supply air volumetric flow rate during cooling operation {m3/s}
    autosize,              !- Supply air volumetric flow rate during heating operation {m3/s}
    autosize,              !- Supply air volumetric flow rate when no cooling or heating is needed {m3/s}
    autosize,              !- Outside air volumetric flow rate during cooling operation {m3/s}
    autosize,              !- Outside air volumetric flow rate during heating operation {m3/s}
    autosize,              !- Outside air volumetric flow rate when no cooling or heating is needed {m3/s}
    FAN:SIMPLE:ONOFF,         !- Supply air fan type
    Zone2PTHPFan,             !- Supply air fan name
    COIL:DX:HEATINGEMPIRICAL,!- Heating coil type
    Zone2PTHPDXHeatCoil,      !- Heating coil name
    0.001,                    !- Heating convergence tolerance {dimensionless}
    2.0,                      !- Minimum outdoor dry-bulb temperature for compressor operation {C}
    COIL:DX:CoolingBypassFactorEmpirical,  !- Cooling coil type
    Zone2PTHPDXCoolCoil,      !- Cooling coil name
    0.001,                    !- Cooling convergence tolerance {dimensionless}
    COIL:ELECTRIC:HEATING,    !- Supplemental heating coil type
    Zone2PTHPSupHeater,       !- Supplemental heating coil name
    autosize,                 !- Maximum supply air temperature from supplemental heater {C}
    10.0,                     !- Maximum outdoor dry-bulb temperature for supplemental heater operation {C}
    blow through,             !- Fan placement
    CyclingFanSch;            !- Heat pump operating mode

SCHEDULE:COMPACT,
    CyclingFanSch,                !- Name
    Fraction,                     !- ScheduleType
    Through: 12/31,               !- Complex Field #1
    For: AllDays,                 !- Complex Field #2
    Until: 24:00,                 !- Complex Field #7
    0.0;                          !- Complex Field #8

OUTSIDE AIR MIXER,
    Zone2PTHPOAMixer,             !- Name
    Zone2PTHPOAMixerOutletNode,   !- Mixed_Air_Node
    Zone2PTHPOAInNode,            !- Outside_Air_Stream_Node
    Zone2PTHPExhNode,             !- Relief_Air_Stream_Node
    Zone2PTHPAirInletNode;        !- Return_Air_Stream_Node

FAN:SIMPLE:ONOFF,
    Zone2PTHPFan,                 !- Fan Name
    FanAndCoilAvailSched,         !- Available Schedule
    0.5,                          !- Fan Total Efficiency
    75.0,                         !- Delta Pressure {Pa}
    autosize,                     !- Max Flow Rate {m3/s}
    0.9,                          !- Motor Efficiency
    1.0,                          !- Motor In Airstream Fraction
    Zone2PTHPOAMixerOutletNode,   !- Fan_Inlet_Node
    Zone2PTHPFanOutletNode;       !- Fan_Outlet_Node

COIL:DX:CoolingBypassFactorEmpirical,
    Zone2PTHPDXCoolCoil,          !- Coil Name
    CoolingCoilAvailSched,        !- Availability Schedule
    autosize,                     !- Rated Total Cooling Capacity (gross) {W}
    autosize,                     !- Rated SHR
    3.0,                          !- Rated COP
    autosize,                     !- Rated Air Volume Flow Rate {m3/s}
    Zone2PTHPFanOutletNode,       !- Coil Air Inlet Node
    Zone2PTHPCoolCoilOutletNode,  !- Coil Air Outlet Node
    HPACCoolCapFT,                !- Total Cooling Capacity Modifier Curve (function of temperature)
    HPACCoolCapFFF,               !- Total Cooling Capacity Modifier Curve (function of flow fraction)
    HPACEIRFT,                    !- Energy Input Ratio Modifier Curve (function of temperature)
    HPACEIRFFF,                   !- Energy Input Ratio Modifier Curve (function of flow fraction)
    HPACPLFFPLR,                  !- Part Load Fraction Correlation (function of part load ratio)
    CycFanCycComp;                !- Supply Air Fan Operation Mode

COIL:DX:HeatingEmpirical,
    Zone2PTHPDXHeatCoil,          !- Coil Name
    HeatingCoilAvailSched,        !- Availability Schedule
    autosize,                     !- Rated Total Heating Capacity {W}
```

```
    2.75,                        !- Rated COP
    autosize,                    !- Rated Air Volume Flow Rate {m3/s}
    Zone2PTHPCoolCoilOutletNode, !- Coil Air Inlet Node
    Zone2PTHPDXHeatCoilOutletNode, !- Coil Air Outlet Node
    HPACHeatCapFT,             !- Total heating capacity modifier curve (function of temperature)
    HPACHeatCapFFF,            !- Total heating capacity modifier curve (function of flow fraction)
    HPACHeatEIRFT,             !- Energy input ratio modifier curve (function of temperature)
    HPACHeatEIRFFF,            !- Energy input ratio modifier curve (function of flow fraction)
    HPACCOOLPLFFPLR,           !- Part load fraction correlation (function of part load ratio)
    ,                          !- Defrost energy input ratio modifier curve (function of temperature)
    CycFanCycComp,             !- Supply Air Fan Operation Mode
    2.0,                       !- Minimum Outdoor Dry-bulb Temperature for Compressor Operation {C}
    5.0,                       !- Maximum Outdoor Dry-bulb Temperature for Defrost Operation {C}
    200.0,                     !- Crankcase Heater Capacity {W}
    10.0,                      !- Maximum Outdoor Dry-bulb Temperature for Crankcase Heater Operation {C}
    Resistive,                 !- Defrost Strategy
    TIMED,                     !- Defrost Control
    0.166667,                  !- Defrost Time Period Fraction
    20000;                     !- Resistive Defrost Heater Capacity {W}

COIL:Electric:Heating,
    Zone2PTHPSupHeater,          !- Coil Name
    HeatingCoilAvailSched,       !- Available Schedule
    1.0,                         !- Efficiency of the Coil
    autosize,                    !- Nominal Capacity of the Coil {W}
    Zone2PTHPDXHeatCoilOutletNode, !- Coil_Air_Inlet_Node
    Zone2PTHPAirOutletNode;      !- Coil_Air_Outlet_Node
```

PackagedTerminal:HeatPump:AirToAir Outputs

```
HVAC,Average,Packaged Terminal Heat Pump Total Zone Heating Rate[W]
HVAC,Sum,Packaged Terminal Heat Pump Total Zone Heating Energy[J]
HVAC,Average,Packaged Terminal Heat Pump Total Zone Cooling Rate[W]
HVAC,Sum,Packaged Terminal Heat Pump Total Zone Cooling Energy[J]
HVAC,Average,Packaged Terminal Heat Pump Sensible Zone Heating Rate[W]
HVAC,Sum,Packaged Terminal Heat Pump Sensible Zone Heating Energy[J]
HVAC,Average,Packaged Terminal Heat Pump Sensible Zone Cooling Rate[W]
HVAC,Sum,Packaged Terminal Heat Pump Sensible Zone Cooling Energy[J]
HVAC,Average,Packaged Terminal Heat Pump Latent Zone Heating Rate[W]
HVAC,Sum,Packaged Terminal Heat Pump Latent Zone Heating Energy[J]
HVAC,Average,Packaged Terminal Heat Pump Latent Zone Cooling Rate[W]
HVAC,Sum,Packaged Terminal Heat Pump Latent Zone Cooling Energy[J]
HVAC,Average,Packaged Terminal Heat Pump Electric Power[W]
HVAC,Sum,Packaged Terminal Heat Pump Electric Consumption[J]
HVAC,Average,Packaged Terminal Heat Pump Fan Part-Load Ratio
HVAC,Average,Packaged Terminal Heat Pump Compressor Part-Load Ratio
```

Packaged Terminal Heat Pump Total Zone Heating Rate[W]

This output field is the total (enthalpy) heat addition rate of the packaged terminal heat pump to the zone it is serving in Watts. This value is calculated using the enthalpy difference of the heat pump outlet air and inlet air streams, and the air mass flow rate through the heat pump. This value is calculated for each HVAC system time step being simulated, and the results (enthalpy addition only) are averaged for the time step being reported.

Packaged Terminal Heat Pump Total Zone Heating Energy[J]

This output field is the total (enthalpy) heat addition of the packaged terminal heat pump to the zone it is serving in Joules over the time step being reported. This value is calculated using the enthalpy difference of the heat pump outlet air and inlet air streams, the air mass flow rate through the heat pump, and the HVAC simulation time step. This value is calculated for each HVAC system time step being simulated, and the results (enthalpy addition only) are summed for the time step being reported.

Packaged Terminal Heat Pump Total Zone Cooling Rate[W]

This output field is the total (enthalpy) heat extraction rate of the packaged terminal heat pump from the zone it is serving in Watts. This value is calculated using the enthalpy difference of the heat pump outlet air and inlet air streams, and the air mass flow rate through the heat pump. This value is calculated for each HVAC system time step being simulated, and the results (enthalpy extraction only) are averaged for the time step being reported.

Packaged Terminal Heat Pump Total Zone Cooling Energy[J]

This output field is the total (enthalpy) heat extraction of the packaged terminal heat pump from the zone it is serving in Joules over the time step being reported. This value is calculated using the enthalpy difference of the heat pump outlet air and inlet air streams, the air mass flow rate through the heat pump, and the HVAC simulation time step. This value is calculated for each HVAC system time step being simulated, and the results (enthalpy extraction only) are summed for the time step being reported.

Packaged Terminal Heat Pump Sensible Zone Heating Rate[W]

This output field is the sensible heat addition rate of the packaged terminal heat pump to the zone it is serving in Watts. This value is calculated using the enthalpy difference of the heat pump outlet air and inlet air streams at a constant humidity ratio, and the air mass flow rate through the heat pump. This value is calculated for each HVAC system time step being simulated, and the results (heating only) are averaged for the time step being reported.

Packaged Terminal Heat Pump Sensible Zone Heating Energy[J]

This output field is the sensible heat addition of the packaged terminal heat pump to the zone it is serving in Joules over the time step being reported. This value is calculated using the enthalpy difference of the heat pump outlet air and inlet air streams at a constant humidity ratio, the air mass flow rate through the heat pump, and the HVAC simulation time step. This value is calculated for each HVAC system time step being simulated, and the results (heating only) are summed for the time step being reported.

Packaged Terminal Heat Pump Sensible Zone Cooling Rate[W]

This output field reports the moist air sensible heat extraction rate of the packaged terminal heat pump from the zone it is serving in Watts. This value is calculated using the enthalpy difference of the heat pump outlet air and inlet air streams at a constant humidity ratio, and the air mass flow rate through the heat pump. This value is calculated for each HVAC system time step being simulated, and the results (cooling only) are averaged for the time step being reported.

Packaged Terminal Heat Pump Sensible Zone Cooling Energy[J]

This output field reports the moist air sensible heat extraction of the packaged terminal heat pump from the zone it is serving in Joules over the time step being reported. This value is calculated using the enthalpy difference of the heat pump outlet air and inlet air streams at a constant humidity ratio, the air mass flow rate through the heat pump, and the HVAC simulation time step. This value is calculated for each HVAC system time step being simulated, and the results (cooling only) are summed for the time step being reported.

Packaged Terminal Heat Pump Latent Zone Heating Rate[W]

This output field is the latent heat addition (humidification) rate of the packaged terminal heat pump to the zone it is serving in Watts. This value is calculated as the difference between the total energy rate and the sensible energy rate provided by the packaged terminal heat pump. This value is calculated for each HVAC system time step being simulated, and the results (latent heat addition only) are averaged for the time step being reported.

Packaged Terminal Heat Pump Latent Zone Heating Energy[J]

This output field is the latent heat addition (humidification) of the packaged terminal heat pump to the zone it is serving in Joules over the time step being reported. This value is calculated as the difference between the total energy delivered to the zone and the sensible energy delivered to the zone by the packaged terminal heat pump. This value is calculated for each HVAC system time step being simulated, and the results (latent heat addition only) are summed for the time step being reported.

Packaged Terminal Heat Pump Latent Zone Cooling Rate[W]

This output field is the latent heat extraction (dehumidification) rate of the packaged terminal heat pump from the zone it is serving in Watts. This value is calculated as the difference between the total energy rate and the sensible energy rate provided by the packaged terminal heat pump. This value is calculated for each HVAC system time step being simulated, and the results (latent heat extraction only) are averaged for the time step being reported.

Packaged Terminal Heat Pump Latent Zone Cooling Energy[J]

This output field is the latent heat extraction (dehumidification) of the packaged terminal heat pump from the zone it is serving in Joules over the time step being reported. This value is calculated as the difference between the total energy delivered to the zone and the sensible energy delivered to the zone by the packaged terminal heat pump. This value is calculated for each HVAC system time step being simulated, and the results (latent heat extraction only) are summed for the time step being reported.

Packaged Terminal Heat Pump Electric Power[W]

This output field is the electricity consumption rate of the packaged terminal heat pump in Watts. The consumption includes electricity used by the compressor (including crankcase heater), fans (indoor supply air fan and the condenser fan), and the supplemental heating coil (if electric). This value is calculated for each HVAC system time step being simulated, and the results are averaged for the time step being reported.

Packaged Terminal Heat Pump Electric Consumption[J]

This output field is the electricity consumption of the packaged terminal heat pump in Joules for the time period being reported. The consumption includes electricity used by the compressor (including crankcase heater), fans (indoor supply air fan and the condenser fan), and the supplemental heating coil (if electric). This value is calculated for each HVAC system time step being simulated, and the results are summed for the time step being reported.

Packaged Terminal Heat Pump Fan Part-Load Ratio

This output field is the part-load ratio of the fan. The fan part-load ratio is defined as the average supply air mass flow rate divided by the maximum supply air mass flow rate. The maximum supply air mass flow rate depends on whether heating, cooling, or no heating or cooling is required during the time step. This value is calculated for each HVAC system time step being simulated, and the results are averaged for the time step being reported.

Packaged Terminal Heat Pump Compressor Part-Load Ratio

This output field is the part-load ratio of the compressor used by the DX coils (cooling and heating). Compressor part-load ratio is defined as the total coil load divided by the coil steady-state capacity. This value is calculated for each HVAC system time step being simulated, and the results are averaged for the time step being reported.

Engineering Document for PackagedTerminalHeatPump:AirToAir

Overview

The packaged terminal heat pump (PTHP) is a compound object made up of other components. Each PTHP consists of an outside air mixer, direct expansion (DX) cooling coil, DX heating coil, supply air fan, and a supplemental heating coil. While the figure below shows the PTHP with draw through fan placement, blow through fan placement can also be modeled by moving the supply air fan before the DX cooling coil. The packaged terminal heat pump coordinates the operation of these components and is modeled as a type of zone equipment (Ref. Zone Equipment List and Controlled Zone Equip Configuration).

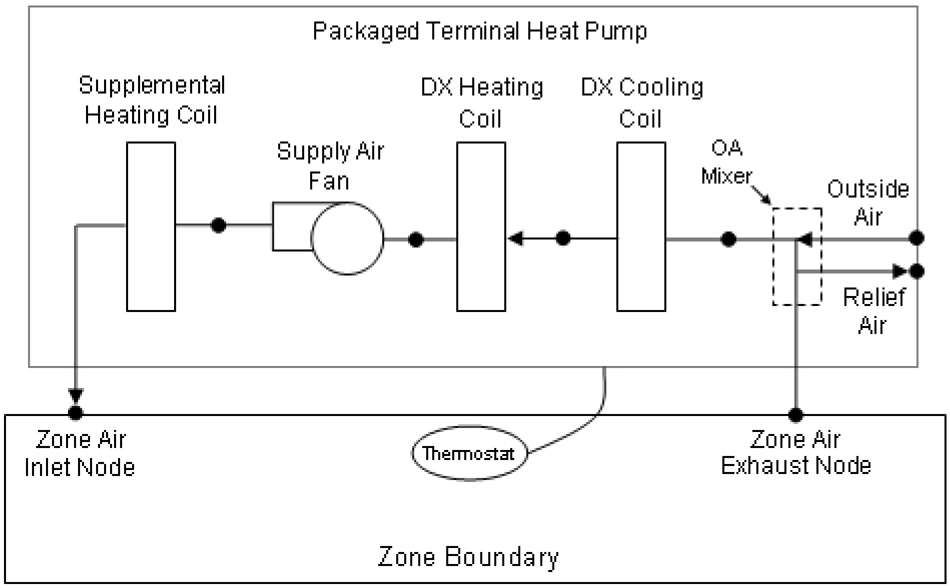


Figure 2. Schematic of a packaged terminal heat pump (draw through fan placement)

The PTHP conditions a single zone and is controlled by a thermostat located in that zone. The PTHP operates to meet the zone sensible cooling or sensible heating requirements as dictated by the thermostat schedule. The model calculates the required part-load ratio for the heat pump's coils and the supply air fan to meet the cooling/heating requirements. The heating or cooling energy provided by the PTHP is delivered to the zone via the zone air inlet node.

The PTHP is able to model supply air fan operation in two modes: cycling fan – cycling coil (i.e., AUTO fan) and continuous fan – cycling coil (i.e., fan ON). Fan:Simple:OnOff must be used to model AUTO fan, while Fan:Simple:OnOff or Fan:Simple:ConstVolume can be used to model fan ON.

Output variables reported by the PTHP object include the supply air fan part-load ratio, the compressor part-load ratio, and the electric consumption of the PTHP. Additional output variables report the total zone heating rate and the total zone cooling rate provided by the heat pump. The sensible and latent components of zone cooling are also available as output variables. Reporting of other variables of interest for the PTHP (DX coil cooling rate, DX coil heating rate, crankcase heater power, fan power, etc.) is done by the individual system components (fan, DX cooling coil, DX heating coil, and supplemental heating coil).

Model Description

As described previously, the PTHP conditions a single zone and is controlled by a zone thermostat (Zone Control:Thermostatic). Each simulation time step, EnergyPlus performs a zone air heat balance to determine if cooling or heating is required to meet the thermostat set points, excluding any impacts from PTHP operation. PTHP performance is then modeled with all heating/cooling coils off but the supply air fan operates as specified by the user. If the zone air heat balance plus the impact of PTHP operation with coils off results in no requirement for heating or cooling by the PTHP coils, or if the PTHP is scheduled off (via its availability schedule), then the PTHP coils do not operate and the compressor part-load ratio output variable is set to 0. If the model determines that cooling or heating is required and the PTHP is scheduled to operate, the model calculates the average air flow rate through the unit and the part-load ratio of the cooling and heating coils in order to meet the thermostat set point temperature.

The remainder of this section describes the calculations performed during the latter situation, when cooling or heating coil operation is required. For any HVAC simulation time step, the PTHP can only be cooling or heating, not both. Because the PTHP cycles its coil(s) on and off to meet the required load, the coil(s) operate for a portion of the time step and are off for the rest of the time step. If the user specifies continuous fan operation (supply air fan operating mode schedule value > 0), then the supply air fan continues to operate at a user-specified flow rate even during periods when the coils cycle off. If the user specifies AUTO fan operation (supply air fan operating mode schedule value = 0), then the supply air fan cycles on and off with the coils. The model accounts for these variations in air flow through the PTHP within a simulation time step when it determines the total cooling or heating energy delivered to the zone, the average supply air conditions and air flow rate, and the energy consumed by the heat pump.

Cooling Operation

If EnergyPlus determines that the heat pump must supply cooling to the zone in order to meet the zone air temperature set point, then the model first calculates the PTHP's sensible cooling rate to the zone under two conditions: when the unit runs at full-load (steady-state) conditions and when the DX cooling coil is OFF. If the supply air fan cycles on/off with the compressor, then the sensible cooling rate is zero when the cooling coil is OFF. However if the fan is configured to run continuously regardless of coil operation, then the sensible cooling rate will not be zero when the cooling coil is OFF. Calculating the sensible cooling rate involves modeling the supply air fan (and associated fan heat), the outside air mixer, and the DX cooling coil. The DX heating coil and the gas or electric supplemental heating coil are also modeled, but only to pass the air properties and mass flow rate from their inlet nodes to their outlet nodes. For each of these cases (full load and DX cooling coil OFF), the sensible cooling rate delivered to the zone by the PTHP is calculated as follows:

$$\dot{Q}_{cooling,max} = \left(\dot{m}_{SA,full\ load}\right)\left(h_{out,full\ load} - h_{zone\ air}\right)_{HRmin}$$

$$\dot{Q}_{cooling,min} = \left(\dot{m}_{SA,coil\ off}\right)\left(h_{out,coil\ off} - h_{zone\ air}\right)_{HRmin}$$

where:

$\dot{Q}_{cooling,max}$ = maximum PTHP sensible cooling rate with cooling coil ON, W

$\dot{m}_{SA,full\ load}$ = supply air mass flow rate at full-load (steady-state) conditions, kg/s

$h_{out,full\ load}$ = enthalpy of air exiting the PTHP at full-load conditions, J/kg

$h_{zone\ air}$ = enthalpy of zone (exhaust) air, J/kg

HR_{min} = enthalpies evaluated at a constant humidity ratio, the minimum humidity ratio of the PTHP exiting air or the zone (exhaust) air

$\dot{Q}_{cooling,min}$ = minimum PTHP sensible cooling rate with cooling coil OFF, W

$\dot{m}_{SA,coil\ off}$ = supply air mass flow rate with the cooling coil OFF, kg/s

$h_{out,coil\ off}$ = enthalpy of air exiting the PTHP with the cooling coil OFF, J/kg

With the calculated PTHP sensible cooling rates and the zone sensible cooling load to be met, the compressor part-load ratio for the PTHP is approximately equal to:

$$PartLoadRatio = MAX\left(0.0, \frac{ABS\left(\dot{Q}_{zone,cooling} - \dot{Q}_{cooling,min}\right)}{ABS\left(\dot{Q}_{cooling,max} - \dot{Q}_{cooling,min}\right)}\right)$$

where:

$PartLoadRatio$ = compressor part-load ratio required to meet the zone load

$\dot{Q}_{zone,cooling}$ = required zone sensible cooling rate to meet set point, W

Since the part-load performance of the DX cooling coil is frequently non-linear (Ref: DX Cooling Coil Model), and the supply air fan heat varies based on cooling coil operation for the case of cycling fan/cycling coil (AUTO fan), the actual part-load ratio for the cooling coil compressor and fan are determined through iterative calculations (successive modeling of the individual PTHP component models) until the PTHP's cooling output (including on/off cycling effects) matches the zone cooling load requirement within the cooling convergence tolerance that is specified.

If the PTHP is specified to operate with cycling fan/cycling coil (AUTO fan), then the user-defined supply air flow rate during cooling operation (volumetric flow rate converted to mass flow rate) is multiplied by the final PartLoadRatio value to determine the average supply air mass flow rate for the HVAC system simulation time step. For this case, the air conditions (temperature, humidity ratio and enthalpy) at nodes downstream of the cooling coil represent the full-load (steady-state) values when the coil is operating. If the supply air fan is specified to operate continuously (fan ON), then the supply air mass flow rate is calculated as the average of the air mass flow rate when the compressor is on and the air mass flow rate when the compressor is off. In this case, the air conditions at nodes downstream of the cooling coil are calculated as the average conditions over the simulation time step (i.e., the weighted average of full-load conditions when the coil is operating and mixed inlet air conditions when the coil is OFF). Additional discussion regarding the calculation of the average supply air flow and supply air conditions is provided later in this section.

Heating Operation

Calculations of the PTHP's sensible heating rate delivered to the zone at full load and with the DX heating coil OFF are identical to the calculations described above for cooling operation.

$$\dot{Q}_{heating,max} = \left(\dot{m}_{SA,full\ load}\right)\left(h_{out,full\ load} - h_{zone\ air}\right)_{HRmin}$$

$$\dot{Q}_{heating,min} = \left(\dot{m}_{SA,coil\ off}\right)\left(h_{out,coil\ off} - h_{zone\ air}\right)_{HRmin}$$

where:

$\dot{Q}_{heating,max}$ = maximum PTHP sensible heating rate with DX heating coil ON, W

$\dot{Q}_{heating,min}$ = minimum PTHP sensible heating rate with DX heating coil OFF, W

With the calculated PTHP sensible heating rates and the zone sensible heating load to be met, the compressor part-load ratio for the PTHP is approximately equal to:

$$PartLoadRatio = MAX\left(0.0, \frac{ABS\left(\dot{Q}_{zone,heating} - \dot{Q}_{heating,min}\right)}{ABS\left(\dot{Q}_{heating,max} - \dot{Q}_{heating,min}\right)}\right)$$

where:

$PartLoadRatio$ = compressor part-load ratio required to meet the zone load

$\dot{Q}_{zone,heating}$ = required zone sensible heating rate to meet set point, W

Iterative calculations (successive modeling of the individual PTHP component models) are used to determine the final heating part-load ratio to account for the non-linear performance of the DX heating coil at part-load conditions and the variation in supply air fan heat for the case of cycling fan/cycling coil (AUTO fan). If DX heating coil operating at full load is unable to meet the entire zone heating load (e.g., the DX heating coil capacity is insufficient or the coil is scheduled OFF, or the outdoor temperature is below the PTHP's minimum outdoor dry-bulb temperature for compressor operation), the supplemental heating coil is activated to meet the remaining zone heating load to the extent possible.

Average Air Flow Calculations

The packaged terminal heat pump operates based on user-specified (or autosized) air flow rates. The PTHP's supply air flow rate during cooling operation may be different than the supply air flow rate during heating operation. In addition, the supply air flow rate when no cooling or heating is required but the supply air fan remains ON can be different than the air flow rates when cooling or heating is required. The outside air flow rates can likewise be different in these various operating modes. The model takes these different flow rates into account when modeling the heat pump, and the average air flow rate for each simulation time step is reported on the inlet/outlet air nodes of the various PTHP components in proportion to the calculated part-load ratio of the DX coil compressor.

The average supply air and outdoor air mass flow rates through the heat pump for the HVAC simulation time step are calculated based on the part-load ratio of the DX cooling coil or DX heating coil (whichever coil is operating) as follows:

$$\dot{m}_{SA,\,avg} = \dot{m}_{SA,comp\ on}\left(PartLoadRatio\right) + \dot{m}_{SA,\,comp\ off}\left(1 - PartLoadRatio\right)$$

$$\dot{m}_{OA,\,avg} = \dot{m}_{OA,\,comp\ on}\left(PartLoadRatio\right) + \dot{m}_{OA,\,comp\ off}\left(1 - PartLoadRatio\right)$$

where:

$\dot{m}_{SA,\,avg}$ = average supply air mass flow rate during the time step, kg/s

$\dot{m}_{SA,comp\ on}$ = supply air mass flow rate when the DX coil compressor is ON, kg/s

$PartLoadRatio$ = part-load ratio of the DX coil compressor (heating or cooling)

$\dot{m}_{SA,\,comp\ off}$ = supply air mass flow rate when the DX coil compressor is OFF, kg/s

$\dot{m}_{OA,\,avg}$ = average outside air mass flow rate during the time step, kg/s

$\dot{m}_{OA,\, comp\ on}$ = average outside air mass flow rate when the DX coil compressor is ON, kg/s

$\dot{m}_{OA,\, comp\ off}$ = average outside air mass flow rate when the DX coil compressor is OFF, kg/s

The supply air and outside air flow rates when the DX cooling or DX heating coil compressor is ON are specified by the user (e.g., supply air volumetric flow rate during cooling operation, supply air volumetric flow rate during heating operation, outside air volumetric air flow rate during cooling operation, and outside air volumetric air flow rate during heating operation) and are converted from volumetric to mass flow rate. If the user has specified cycling fan operation (supply air fan operating mode schedule value = 0), then the supply air and outside air mass flow rates when the DX compressor is OFF are zero. If the user has specified constant fan operation (supply air fan operating mode schedule value > 0), then the user-defined air flow rates when no cooling or heating is needed are used when the DX compressor is OFF.

There is one special case. If the user has specified constant fan operation (supply air fan operating mode schedule value > 0) and they specify that the supply air volumetric flow rate when no cooling or heating is needed is zero (or field is left blank), then the model assumes that the supply air and outside air mass flow rates when the DX coil compressor is OFF are equal to the corresponding air mass flow rates when the compressor was last operating (ON).

Calculation of Outlet Air Conditions

When the supply air fan cycles on and off with the PTHP coils (AUTO fan), the calculated outlet air conditions (temperature, humidity ratio, and enthalpy) from the DX heating or DX cooling coil at full-load (steady-state) operation are reported on the appropriate coil outlet air node. The air mass flow rate reported on the air nodes is the average air mass flow rate proportional to the part-load ratio of the DX coil compressor (see Average Air Flow Calculations above).

When the supply air fan operates continuously while the PTHP coils cycle on and off (fan ON), the air mass flow rate reported on the air nodes is the average air mass flow rate proportional to the part-load ratio of the DX coil compressor (see Average Air Flow Calculations above). Since the air flow rate can be different when the coil is ON compared to when the coil is OFF, then the average outlet air conditions from the DX heating or DX cooling coil are reported on the appropriate coil outlet air node.

Refer to the sections in the document that describe the DX heating and DX cooling coils for further explanation on how they report their outlet air conditions.

Calculation of Zone Heating and Cooling Rates

At the end of each HVAC simulation time step, this compound object reports the heating or cooling rate and energy delivered to the zone, as well as the electric power and consumption by the heat pump. In terms of thermal energy delivered to the zone, the sensible, latent and total energy transfer rate to the zone is calculated as follows:

$$\dot{Q}_{Total} = \left(\dot{m}_{SA,\, avg}\right)\left(h_{out,avg} - h_{zone\ air}\right)$$

$$\dot{Q}_{Sensible} = \left(\dot{m}_{SA,\, avg}\right)\left(h_{out,avg} - h_{zone\ air}\right)_{HRmin}$$

$$\dot{Q}_{Latent} = \dot{Q}_{Total} - \dot{Q}_{Sensible}$$

where:

$\dot{Q}_{Total}$ = total energy transfer rate to the zone, W

$\dot{Q}_{Sensible}$ = sensible energy transfer rate to the zone, W

$\dot{Q}_{Latent}$ = latent energy transfer rate to the zone, W

$\dot{m}_{SA,\,avg}$ = average mass flow rate of the supply air stream, kg/s

$h_{out,avg}$ = enthalpy of the air being supplied to the zone, J/kg

Since each of these energy transfer rates can be calculated as positive or negative values, individual reporting variables are established for cooling and heating and only positive values are reported. The following calculations are representative of what is done for each of the energy transfer rates:

IF ($\dot{Q}_{Total} < 0.0$) THEN

$\dot{Q}_{TotalCooling}$ = ABS ($\dot{Q}_{Total}$)

$\dot{Q}_{TotalHeating} = 0.0$

ELSE

$\dot{Q}_{TotalCooling} = 0.0$

$\dot{Q}_{TotalHeating} = \dot{Q}_{Total}$

where:

$\dot{Q}_{TotalCooling}$ = output variable 'Packaged Terminal Heat Pump Total Zone Cooling Rate, W'

$\dot{Q}_{TotalHeating}$ = output variable 'Packaged Terminal Heat Pump Total Zone Heating Rate, W'

In addition to heating and cooling rates, the heating and cooling energy supplied to the zone is also calculated for the time step being reported. The following example for total zone cooling energy is representative of what is done for the sensible and latent energy as well as the heating counterparts.

$$Q_{TotalCooling} = \dot{Q}_{TotalCooling} * TimeStepSys * 3600.$$

where:

$Q_{TotalCooling}$ = output variable 'Packaged Terminal Heat Pump Total Zone Cooling Energy, J'

$TimeStepSys$ = HVAC system simulation time step, hr

Appendix B

EnergyPlus Documentation for Modeling Multispeed Air-to-Air Heat Pumps with Waste Heat Recovery

This appendix contains the EnergyPlus documentation (Input/Output Reference and Engineering Manual sections) for the multispeed air-to-air heat pump model and associated cooling and heating coil models that were added as part of this project.

Input Output Reference for UnitarySystem:MultiSpeedHeatPump:AirToAir

The multispeed air-to-air heat pump is a "virtual" component that consists of a fan component (On/Off or ConstVolume), a DX multispeed cooling coil component, a DX multispeed heating coil component, and a GAS or ELECTRIC supplemental heating coil component. This system also includes the option to use available waste energy to heat water. A schematic diagram of the air-to-air multispeed heat pump is shown below. The component connection sequence for the blow through option (shown below) from inlet to outlet is fan, cooling coil, heating coil, and supplemental heater. The connection sequence for the draw through option is cooling coil, heating coil, fan, and supplemental heater.

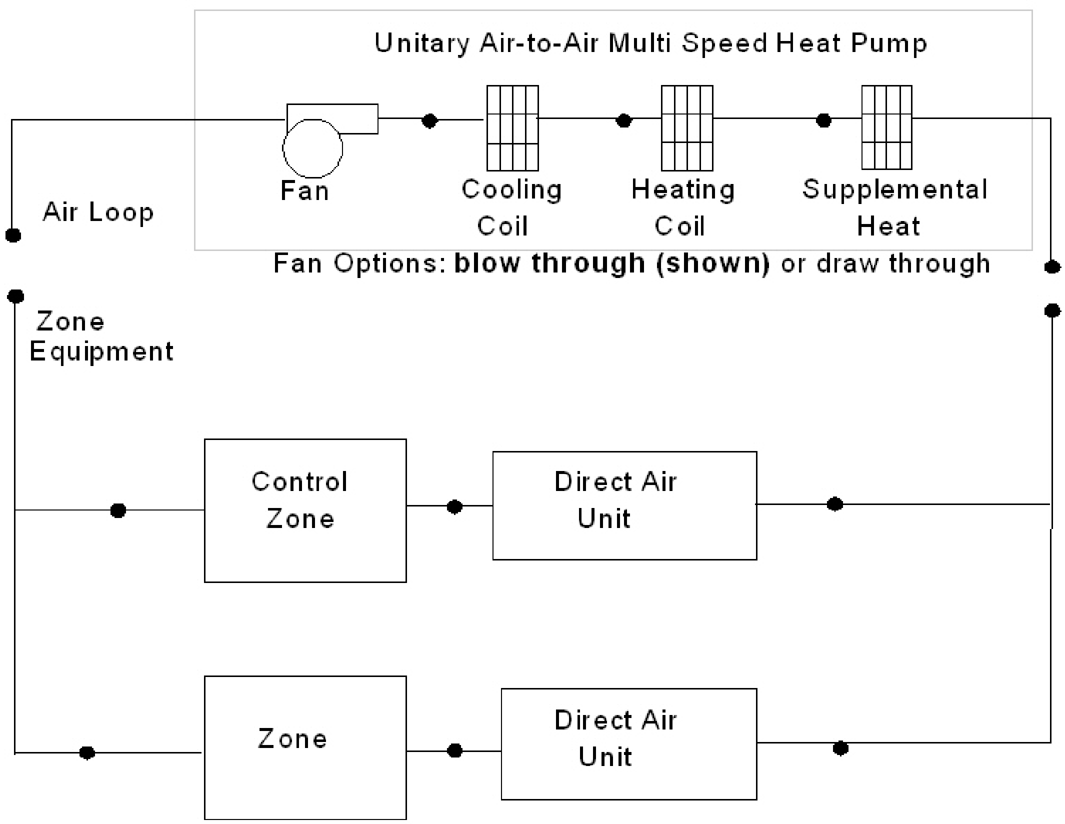


Figure 3. Schematic of EnergyPlus Unitary Air-to-Air Multi Speed Heat Pump

The main difference between this heat pump object and other EnergyPlus heat pump objects is that this object allows from two to four discrete compressor speeds for heating and cooling operation (instead of a single speed for each mode). The lowest speed is called Speed 1, and the highest speed is called Speed n (2, 3 or 4 as specified in the input syntax). This object allows a different number of speeds for cooling and heating, and each speed has an associated airflow rate. The airflow rates for the various heating speeds can be different from the airflow rates for the cooling speeds. In addition, the airflow rate when no cooling or heating is needed can also be defined. The number of cooling and heating speeds defined by the user in this heat pump object must equal the number of speeds defined in the associated coils (child objects). For example, the number of speeds for cooling defined in this heat pump object must be equal to the number of speeds defined in the associated cooling coil object.

Links to the fan, DX multispeed cooling coil, DX multispeed heating coil, and supplementary heating coil specifications are provided in the heat pump's input data syntax. In addition, the control zone name, airflow rates at the corresponding compressor speeds, and the fraction of total system air flow delivered to the control zone are specified by the heat pump syntax. The object inputs are shown in the Energy+.idd specification below.

```
UNITARYSYSTEM:MULTISPEEDHEATPUMP:AIRTOAIR,
        \min-fields 32
   A1,  \field Name of multispeed heat pump
        \required-field
        \type alpha
   A2,  \field Availability schedule name
        \required-field
        \type object-list
        \object-list ScheduleNames
   A3,  \field Heat pump air inlet node name
        \required-field
        \type alpha
   A4,  \field Heat pump air outlet node name
        \required-field
        \type alpha
   A5,  \field Controlling zone or thermostat location
        \required-field
        \type object-list
        \object-list ZoneNames
   N1,  \field Fraction of the total volume flow that goes through the controlling zone
        \required-field
        \type real
        \minimum> 0
        \maximum 1
        \autosizable
   A6,  \field Supply air fan type
        \required-field
        \type choice
        \key FAN:SIMPLE:ONOFF
        \key FAN:SIMPLE:CONSTVOLUME
        \note Select the type of supply air fan used in this unitary system.
   A7,  \field Supply air fan name
        \required-field
        \type object-list
        \object-list FansCVandOnOff
        \note Enter the name of the supply air fan used in this unitary system.
   A8,  \field Supply air fan placement
        \required-field
        \type choice
        \key blow through
        \key draw through
        \note Select supply air fan placement as either blow through or draw through.
        \note Blow through means the supply air fan is located before the cooling
        \note coil. Draw through means the supply air fan is located after the heating coil
        \note but before the optional supplemental heating coil.
   A9 , \field Supply air fan operating mode schedule name
        \type object-list
        \object-list ScheduleNames
        \note Enter the name of a schedule to control the supply air fan. Schedule values of zero
        \note mean that the supply air fan will cycle off if there is no cooling or heating load
        \note in the control zone. Non-zero schedule values mean that the supply air fan
        \note will operate continuously even if there is no cooling or heating load
```

```
      \note in the control zone. If this field is left blank, the supply air fan will
      \note operate continuously for the entire simulation period.
 A10, \field Heating coil type
      \required-field
      \type choice
      \key COIL:DX:MultiSpeed:Heating
      \note Only works with COIL:DX:MultiSpeed:Heating
 A11, \field Heating coil name
      \required-field
      \type object-list
      \object-list HeatingCoilsDX
      \note Needs to match in the DX heating coil object
 N2 , \field Minimum outdoor dry-bulb temperature for compressor operation
      \type real
      \minimum -20.0
      \default -8.0
      \units C
      \note Needs to match the corresponding minimum outdoor temperature defined
      \note in the DX heating coil object.
 A12, \field Cooling coil type
      \required-field
      \type choice
      \key COIL:DX:MultiSpeed:Cooling
      \note Only works with COIL:DX:MultiSpeed:Cooling
 A13, \field Cooling coil name
      \required-field
      \note Needs to match in the DX cooling coil object
      \type object-list
      \object-list CoolingCoilsDX
 A14, \field Supplemental heating coil type
      \type choice
      \key COIL:GAS:HEATING
      \key COIL:ELECTRIC:HEATING
 A15, \field Supplemental heating coil name
      \type object-list
      \object-list HeatingCoilsGasElec
      \note Needs to match in the supplemental heating coil object
 N3 , \field Maximum supply air temperature from supplemental heater
      \type real
      \units C
      \autosizable
 N4 , \field Maximum outdoor dry-bulb temperature for supplemental heater operation
      \type real
      \maximum 21.0
      \default 21.0
      \units C
 N5 , \field Auxiliary On-Cycle Electric Power
      \type real
      \units W
      \minimum 0
      \default 0
 N6 , \field Auxiliary Off-Cycle Electric Power
      \type real
      \units W
      \minimum 0
      \default 0
 N7 , \field Design Heat Recovery Water Flow Rate
      \type real
      \note If non-zero, then the inlet and outlet node names MUST be entered.
      \note Used for heat recovery to an EnergyPlus water (plant) loop.
      \units m3/s
      \minimum 0.0
      \default 0.0
 N8,  \field Maximum Temp for Heat Recovery
      \units C
      \maximum 100.0
      \minimum 0.0
      \default 80.0
 A16, \field Heat recovery water inlet node name
      \type alpha
 A17, \field Heat recovery water outlet node name
```

```
      \type alpha
  N9 , \field Supply air volumetric flow rate when no cooling or heating is needed
      \type real
      \units m3/s
      \minimum 0
      \autosizable
      \note Only used when the supply air fan operating mode is continuous (see field
      \note Supply air fan operating mode schedule name). This air flow rate
      \note is used when no heating or cooling is required and the coils are off.
      \note If this field is left blank or zero, the supply air flow rate from the
      \note previous on cycle (either cooling or heating) is used.
  N10, \field Number of speeds for heating
      \required-field
      \type integer
      \minimum 2
      \maximum 4
      \note Enter the number of the following sets of data for air flow rates.
  N11, \field Number of speeds for cooling
      \required-field
      \type integer
      \minimum 2
      \maximum 4
      \note Enter the number of the following sets of data for air flow rates.
  N12, \field Supply air volumetric flow rate during heating operation, Speed 1
      \required-field
      \type real
      \units m3/s
      \autosizable
      \minimum> 0
      \note Enter the operating supply air volumetric flow rate during heating
      \note operation or specify autosize.
  N13, \field Supply air volumetric flow rate during heating operation, Speed 2
      \required-field
      \type real
      \units m3/s
      \autosizable
      \minimum> 0
      \note Enter the operating supply air volumetric flow rate during heating
      \note operation or specify autosize.
  N14, \field Supply air volumetric flow rate during heating operation, Speed 3
      \required-field
      \type real
      \units m3/s
      \autosizable
      \minimum> 0
      \note Enter the operating supply air volumetric flow rate during heating
      \note operation or specify autosize.
  N15, \field Supply air volumetric flow rate during heating operation, Speed 4
      \required-field
      \type real
      \units m3/s
      \autosizable
      \minimum> 0
      \note Enter the operating supply air volumetric flow rate during heating
      \note operation or specify autosize.
  N16, \field Supply air volumetric flow rate during cooling operation, Speed 1
      \type real
      \units m3/s
      \autosizable
      \minimum> 0
      \note Enter the operating supply air volumetric flow rate during cooling
      \note operation or specify autosize.
  N17, \field Supply air volumetric flow rate during cooling operation, Speed 2
      \type real
      \units m3/s
      \autosizable
      \minimum> 0
      \note Enter the operating supply air volumetric flow rate during cooling
      \note operation or specify autosize.
  N18, \field Supply air volumetric flow rate during cooling operation, Speed 3
      \type real
```

```
       \units m3/s
       \autosizable
       \minimum> 0
       \note Enter the operating supply air volumetric flow rate during cooling
       \note operation or specify autosize.
  N19; \field Supply air volumetric flow rate during cooling operation, Speed 4
       \type real
       \units m3/s
       \autosizable
       \minimum> 0
       \note Enter the operating supply air volumetric flow rate during cooling
       \note operation or specify autosize.
```

Field: Name of multispeed heat pump

This alpha field contains the identifying name for the multispeed heat pump.

Field: Availability schedule name

This alpha field contains the schedule name (ref. Schedule) that contains information on the availability of the heat pump to operate. A schedule value greater than 0 (usually 1 is used) indicates that the unit can be on during the hour. A value less than or equal to 0 (usually 0 is used) denotes that the unit must be off for the hour.

Field: Heat pump air inlet node name

This alpha field contains the name of the HVAC system node from which the heat pump draws its inlet air.

Field: Heat pump air outlet node name

This alpha field contains the name of the HVAC system node to which the heat pump sends its outlet air.

Field: Controlling zone or thermostat location

This alpha field contains the identifying zone name where the thermostat controlling the multispeed heat pump is located.

Field: Fraction of the total volume flow that goes through the controlling zone

This numeric field contains the fraction (>0 to 1) of the total system volumetric flow rate that is supplied to the zone where the thermostat controlling the multispeed heat pump is located.

Field: Supply air fan type

This alpha field contains the identifying type of supply air fan specified for the heat pump. Fan type must be FAN:SIMPLE:ONOFF or FAN:SIMPLE:CONSTVOLUME. FAN:SIMPLE:CONSTVOLUME can only be used when the supply air fan operating mode is continuous (see field ‘Supply air fan operating mode schedule name).

Field: Supply air fan name

This alpha field contains the identifying name given to the heat pump supply air fan, and should match the name specified in the corresponding fan object.

Field: Supply air fan placement

This alpha field has two choices: blow through or draw through. The first choice stands for “blow through fan”. This means that the unit consists of a fan followed by a DX multispeed cooling coil, DX multispeed heating coil, and a supplemental heating coil. The fan “blows through” the cooling and heating coils. The second choice stands for “draw through fan”. This means that the unit consists of the DX cooling and heating coils followed by a fan, with the supplemental heater located at the outlet of the fan. The fan "draws" air through the DX coils.

> Note: the multispeed heat pump's supply air fan, cooling coil, heating coil and supplemental heating coil must be connected according to the configuration shown above (Figure 3) for the 'blow through' fan configuration. For the 'draw through' fan configuration the fan must be located between the DX heating coil and the supplemental heater, whose outlet node is the system outlet node. In addition, the DX cooling coil and DX heating coil operation mode must be specified consistently with the heat pump's supply air fan operating mode (e.g., with the heat pump's supply air fan set to cycle on and off with the cooling/heating load, the DX cooling and heating coil operation mode must be CycFanCycComp). If the operation modes in the parent (heat pump) and child (coil) objects are specified differently, the operation mode in the parent object prevails.

Field: Supply air fan operating mode schedule name

This alpha field contains the schedule name (ref. Schedule) that contains information to control the supply air fan. Schedule values of zero mean that the supply air fan will cycle off if there is no cooling or heating load in the control zone. Non-zero schedule values mean that the supply air fan will operate continuously even if there is no cooling or heating load in the control zone. If this field is left blank, the supply air fan will operate continuously for the entire simulation period.

Field: Heating coil type

This alpha field contains the identifying type of heating coil specified in the heat pump. Heating coil type must be Coil:DX:MultiSpeed:Heating.

Field: Heating coil name

This alpha field contains the identifying name given to the DX heating coil, and should match the name specified in the corresponding DX heating coil object.

Field: Minimum outdoor dry-bulb temperature for compressor operation

This numeric field defines the outdoor air dry-bulb temperature below which the DX heating coil turns off. The temperature for this input field must be greater than or equal to –20 C. If this input field is left blank, the default value is -8 C. This temperature should match the minimum compressor operating temperature specified for the multispeed heat pump's DX heating coil.

Field: Cooling coil type

This alpha field contains the identifying type of cooling coil specified in the heat pump. Cooling coil type must be Coil:DX:MultiSpeed:Cooling.

Field: Cooling coil name

This alpha field contains the identifying name given to the heat pump cooling coil, and should match the name specified in the corresponding DX cooling coil object.

Field: Supplemental heating coil type

This alpha field contains the identifying type of supplemental heating coil specified in the heat pump. Heating coil type must be Coil:Gas:Heating or Coil:Electric:Heating.

Field: Supplemental heating coil name

This alpha field contains the identifying name given to the heat pump supplemental heating coil, and should match the name specified in the corresponding heating coil object.

Field: Maximum supply air temperature from supplemental heater

This numeric field defines the maximum allowed supply air temperature (in degrees C) exiting the heat pump supplemental heating coil. If the calculated supply air temperature exiting the supplemental heater exceeds this value, then it is reset to this maximum temperature. This field is autosizable.

Field: Maximum outdoor dry-bulb temperature for supplemental heater operation

This numeric field defines the outdoor air dry-bulb temperature above which the heat pump supplemental heating coil is disabled. The temperature for this input field must be less than or equal to 21 C. If this input field is left blank, the default value is 21 C.

Field: Auxiliary On-Cycle Electric Power

This field defines auxiliary electrical power (W) consumed during the on-cycle period (i.e., when the cooling or heating coil is operating). The model assumes that this auxiliary power does not contribute to heating the supply air. The minimum value for this field is 0.0, and the default value is also 0.0 if the field is left blank.

Field: Auxiliary Off-Cycle Electric Power

This field defines auxiliary electrical power (W) consumed during the off-cycle period (i.e., when the cooling and heating coil are not operating). The model assumes that this auxiliary power does not contribute to heating the supply air. The minimum value for this field is 0.0, and the default value is also 0.0 if the field is left blank.

Field: Design Heat Recovery Water Flow Rate

This optional input field defines the design water flow rate used if the heat recovery option is being simulated. If this value is greater than 0.0 then a heat recovery loop must be specified and attached to the multispeed heat pump using the next 2 node fields. To determine how the heat recovery algorithm works, refer to the EnergyPlus Engineering Reference in the UNITARYSYSTEM:MULTISPEEDHEATPUMP: AIRTOAIR with Heat Recovery section. The units for this input value are cubic meters per second.

Field: Maximum Temp for Heat Recovery

This field sets the maximum temperature (in degrees C) that this heat pump can produce for heat recovery. The idea behind this field is that the current models do not take temperatures into account for availability and they just pass Q's around the loop without a temperature limit. This temperature limit puts an upper bound on the recovered heat and limits the max temperature leaving the component.

As temperatures in the loop approach the maximum temperature, the temperature difference between the entering water and the surfaces in the piece of equipment becomes smaller. For the given heat recovery flow rate and that temperature difference the amount of heat recovered will be reduced, and eventually there will be no heat recovered when the entering water temperature is equal to the maximum temperature specified by the user in this field. The reduced amount of heat recovered will diminish if the temperature of the loop approach is the maximum temperature, and this will show up in the reporting. This allows the user to set the availability or the quality of the heat recovered for usage in other parts of the system or to heat domestic hot water supply.

Field: Heat recovery water inlet node

This alpha field contains the identifying name for the heat recovery side inlet node.

Field: Heat recovery water outlet node

This alpha field contains the identifying name for the heat recovery side outlet node.

Field: Supply air volumetric flow rate when no cooling or heating is needed

This numeric field defines the supply air flow rate leaving the heat pump in cubic meters per second when neither cooling nor heating is required (i.e., DX coils and supplemental heater are off but the supply air fan operates). This field is only used when the heat pump supply air fan is scheduled to operate continuously regardless of DX coil operation (ref. field "Supply air fan operating mode schedule). Values must be greater than or equal to zero, or this field is autosizable. If the heat pump supply air fan is scheduled to operate continuously and the input value for this field is set to zero or this field is left blank, then the model assumes that the supply air flow rate when no cooling/heating is needed is equal to the supply air flow rate when the compressor was last operating (for cooling operation or heating operation).

Field: Number of speeds for heating

This field defines the number of heating speeds for the heat pump, and must match the number of heating speeds defined in the associated heating coil. The value for this input field defines the number of airflow rates that must be defined for heating in the field below. The minimum value for this field is two and the maximum value is four.

Field: Number of speeds for cooling

This field defines the number of cooling speeds for the heat pump, and must match the number of cooling speeds defined in the associated DX cooling coil. The value for this input field defines the number of airflow rates that must be defined for cooling in the field below. The minimum value for this field is two and the maximum value is four.

Field: Supply air volumetric flow rate during heating operation, Speed 1

This required numeric field defines the supply air flow rate leaving the heat pump in cubic meters per second when the DX heating coil and/or supplemental heater are operating at Speed 1 (lowest speed). Values must be greater than 0 or this field is autosizable.

Field: Supply air volumetric flow rate during heating operation, Speed 2

This required numeric field defines the supply air flow rate leaving the heat pump in cubic meters per second when the DX heating coil and/or supplemental heater are operating at Speed 2. Values must be greater than 0 or this field is autosizable. If not autosized, the entered value must be greater or equal to the flow rate specified for heating Speed 1.

Field: Supply air volumetric flow rate during heating operation, Speed 3

This numeric field defines the supply air flow rate leaving the heat pump in cubic meters per second when the DX heating coil and/or supplemental heater are operating at Speed 3. Values must be greater than 0 or this field is autosizable. If not autosized, the entered value must be greater or equal to the flow rate specified for heating Speed 2. If the 'Number of speeds for heating' is less than 3, then this field is not needed.

Field: Supply air volumetric flow rate during heating operation, Speed 4

This numeric field defines the supply air flow rate leaving the heat pump in cubic meters per second when the DX heating coil and/or supplemental heater are operating at Speed 4 (high speed). Values must be greater than 0 or this field is autosizable. If not autosized, the entered value must be greater or equal to the flow rate specified for heating Speed 3. If the 'Number of speeds for heating' is less than 4, then this field is not needed.

Note: When autosizable is selected for any of the supply air volumetric flow rate fields, all supply air flow fields at the different speeds must be specified as autosizable. Otherwise, a fatal error will be issued and the simulation will terminate.

Field: Supply air volumetric flow rate during cooling operation, Speed 1

This required numeric field defines the supply air flow rate leaving the heat pump in cubic meters per second when the DX cooling coil is operating at Speed 1 (lowest speed). Values must be greater than 0 or this field is autosizable.

Field: Supply air volumetric flow rate during cooling operation, Speed 2

This required numeric field defines the supply air flow rate leaving the heat pump in cubic meters per second when the DX cooling coil is operating at Speed 2. Values must be greater than 0 or this field is autosizable. If not autosized, the entered value must be greater or equal to the flow rate specified for cooling Speed 1.

Field: Supply air volumetric flow rate during cooling operation, Speed 3

This numeric field defines the supply air flow rate leaving the heat pump in cubic meters per second when the DX cooling coil is operating at Speed 3. Values must be greater than 0 or this field is autosizable. If not autosized, the entered value must be greater or equal to the flow rate specified for cooling Speed 2. If the ‘Number of speeds for cooling’ is less than 3, then this field is not needed

Field: Supply air volumetric flow rate during cooling operation, Speed 4

This numeric field defines the supply air flow rate leaving the heat pump in cubic meters per second when the DX cooling coil is operating at Speed 4 (highest speed). Values must be greater than 0 or this field is autosizable. If not autosized, the entered value must be greater or equal to the flow rate specified for cooling Speed 3. If the ‘Number of speeds for cooling’ is less than 4, then this field is not needed

Following is an example input for a UnitarySystem:MultiSpeedHeatPump:AirToAir and its associated components.

UnitarySystem:MultiSpeedHeatPump:AirToAir Example Specification

```
UNITARYSYSTEM:MULTISPEEDHEATPUMP:AIRTOAIR,
  DXAC Heat Pump 1,         !- Name of multispeed heat pump
  FanAndCoilAvailSched,     !- Availability schedule
  Mixed Air Node,           !- Heat pump air inlet node name
  Air Loop Outlet Node,     !- Heat pump air outlet node name
  East Zone,                !- Controlling zone or thermostat location
  0.28,                     !- Fraction of the total volume flow that goes through the
                            !- controlling zone
  FAN:SIMPLE:ONOFF,         !- Supply air fan type
  Supply Fan 1,             !- Supply air fan name
  blow through,             !- Supply air fan placement
  FanModeSchedule,          !- Supply air fan operating mode schedule name
  COIL:DX:MultiSpeed:Heating,    !- Heating coil type
  Heat Pump DX Heating Coil 1,  !- Heating coil name
  -8.0,                     !- Minimum outdoor dry-bulb temperature for compressor operation
  COIL:DX:MultiSpeed:Cooling,  !- Cooling coil type
  Heat Pump ACDXCoil 1,     !- Cooling coil name
  COIL:GAS:HEATING,         !- Supplemental heating coil type
  Supp Gas Heating Coil 1,  !- Supplemental heating coil name
  50.0,                     !- Maximum supply air temperature from supplemental heater
  21,                       !- Maximum outdoor dry-bulb temperature for supplemental heater
                            !- operation {C}
  0,                        !- Auxiliary On-Cycle Electric Power {W}
  0,                        !- Auxiliary Off-Cycle Electric Power {W}
  0.00,                     !- Design Heat Recovery Water Flow Rate {m3/s}
  80.0,                     !- Maximum Temp for Heat Recovery {C}
  ,                         !- Heat recovery water inlet node name
  ,                         !- Heat recovery water outlet node name
  0.2,                      !- Supply air volumetric flow rate when no cooling or heating is
                            !- needed {m3/s}
  4,                        !- Number of speeds for heating
  4,                        !- Number of speeds for cooling
  0.4,                      !- Supply air volumetric flow rate during heating operation, Speed 1
                            !- {m3/s}
  0.8,                      !- Supply air volumetric flow rate during heating operation, Speed 2
                            !- {m3/s}
  1.2,                      !- Supply air volumetric flow rate during heating operation, Speed 3
                            !- {m3/s}
  1.7,                      !- Supply air volumetric flow rate during heating operation, Speed 4
                            !- {m3/s}
  0.4,                      !- Supply air volumetric flow rate during cooling operation, Speed 1
                            !- {m3/s}
  0.8,                      !- Supply air volumetric flow rate during cooling operation, Speed 2
                            !- {m3/s}
  1.2,                      !- Supply air volumetric flow rate during cooling operation, Speed 3
                            !- {m3/s}
  1.7;                      !- Supply air volumetric flow rate during cooling operation, Speed 4
                            !- {m3/s}

COIL:DX:MultiSpeed:Heating,
  Heat Pump DX Heating Coil 1,  !- Name of heat pump heating coil
  FanAndCoilAvailSched,     !- Availability Schedule
  Heating Coil Air Inlet Node,  !- Coil Air Inlet Node
  SuppHeating Coil Air Inlet Node,  !- Coil Air Outlet Node
  CycFanCycComp,            !- Supply Air Fan Operation Mode
  -8.0,                     !- Minimum Outdoor Dry-bulb Temperature for Compressor Operation {C}
  200.0,                    !- Crankcase Heater Capacity {W}
  10.0,                     !- Maximum Outdoor Dry-bulb Temperature for Crankcase Heater
                            !- Operation {C}
  HPACDefrostCAPFT,         !- Defrost energy input ratio modifier curve (temperature)
  7.22,                     !- Maximum Outdoor Dry-bulb Temperature for Defrost Operation
  reverse-cycle,            !- Defrost Strategy
  timed,                    !- Defrost Control
  0.058333,                 !- Defrost Time Period Fraction
  2000.0,                   !- Resistive Defrost Heater Capacity {W}
  No,                       !- Apply Part Load Fraction to Speeds greater than 1
```

```
  NaturalGas,              !- Fuel type
  4,                       !- Number of speeds
  7500,                    !- Rated Total Heating Capacity, Speed 1 {W}
  2.75,                    !- Rated COP, Speed 1
  0.45,                    !- Rated Air Volume Flow Rate, Speed 1 {m3/s}
  HPACHeatCapFT Speed 1,   !- Total Heating Capacity Modifier Curve, Speed 1 (temperature)
  HPACHeatCapFF Speed 1,   !- Total Heating capacity modifier curve, Speed 1 (flow fraction)
  HPACHeatEIRFT Speed 1,   !- Energy input ratio modifier curve, Speed 1 (temperature)
  HPACHeatEIRFF Speed 1,   !- Energy input ratio modifier curve, Speed 1 (flow fraction)
  HPACHeatPLFFPLR Speed 1, !- Part load fraction correlation, Speed 1 (part load ratio)
  0.2,                     !- Rated waste heat fraction of power input, Speed 1
  HAPCHeatWHFT Speed 1,    !- Waste heat modifier curve, Speed 1 (temperature)
  17500,                   !- Rated Total Heating Capacity, Speed 2 {W}
  2.75,                    !- Rated COP, Speed 2
  0.85,                    !- Rated Air Volume Flow Rate, Speed 2 {m3/s}
  HPACHeatCapFT Speed 2,   !- Total Heating Capacity Modifier Curve, Speed 2 (temperature)
  HPACHeatCapFF Speed 2,   !- Total Heating capacity modifier curve, Speed 2 (flow fraction)
  HPACHeatEIRFT Speed 2,   !- Energy input ratio modifier curve, Speed 2 (temperature)
  HPACHeatEIRFF Speed 2,   !- Energy input ratio modifier curve, Speed 2 (flow fraction)
  HPACHeatPLFFPLR Speed 2, !- Part load fraction correlation, Speed 2 (part load ratio)
  0.2,                     !- Rated waste heat fraction of power input, Speed 2
  HAPCHeatWHFT Speed 2,    !- Waste heat modifier curve, Speed 2 (temperature)
  25500,                   !- Rated Total Heating Capacity, Speed 3 {W}
  2.75,                    !- Rated COP, Speed 3
  1.25,                    !- Rated Air Volume Flow Rate, Speed 3 {m3/s}
  HPACHeatCapFT Speed 3,   !- Total Heating Capacity Modifier Curve, Speed 3 (temperature)
  HPACHeatCapFF Speed 3,   !- Total Heating capacity modifier curve, Speed 3 (flow fraction)
  HPACHeatEIRFT Speed 3,   !- Energy input ratio modifier curve, Speed 3 (temperature)
  HPACHeatEIRFF Speed 3,   !- Energy input ratio modifier curve, Speed 3 (flow fraction)
  HPACHeatPLFFPLR Speed 3, !- Part load fraction correlation, Speed 3 (part load ratio)
  0.2,                     !- Rated waste heat fraction of power input, Speed 3
  HAPCHeatWHFT Speed 3,    !- Waste heat modifier curve, Speed 3 (temperature)
  35500,                   !- Rated Total Heating Capacity, Speed 4 {W}
  2.75,                    !- Rated COP, Speed 4
  1.75,                    !- Rated Air Volume Flow Rate, Speed 4 {m3/s}
  HPACHeatCapFT Speed 4,   !- Total Heating Capacity Modifier Curve, Speed 4 (temperature)
  HPACHeatCapFF Speed 4,   !- Total Heating capacity modifier curve, Speed 4 (flow fraction)
  HPACHeatEIRFT Speed 4,   !- Energy input ratio modifier curve, Speed 4 (temperature)
  HPACHeatEIRFF Speed 4,   !- Energy input ratio modifier curve, Speed 4 (flow fraction)
  HPACHeatPLFFPLR Speed 4, !- Part load fraction correlation, Speed 4 (part load ratio)
  0.2,                     !- Rated waste heat fraction of power input, Speed 4
  HAPCHeatWHFT Speed 4;    !- Waste heat modifier curve, Speed 4 (temperature)

COIL:DX:MultiSpeed:Cooling,
  Heat Pump ACDXCoil 1,    !- Coil Name
  FanAndCoilAvailSched,    !- Availability Schedule
  DX Cooling Coil Air Inlet Node,  !- Coil Air Inlet Node
  Heating Coil Air Inlet Node,  !- Coil Air Outlet Node
  CycFanCycComp,           !- Supply Air Fan Operation Mode
  Outdoor Condenser Air Node, !- Condenser Air Inlet Node Name
  AIR COOLED,              !- Condenser Type
  ,                        !- Name of Water Storage Tank for Supply
  ,                        !- Name of Water Storage Tank for Condensate Collection
  No,                      !- Apply Part Load Fraction to Speeds greater than 1
  No,                      !- Apply Latent Degradation to Speeds greater than 1
  200.0,                   !- Crankcase Heater Capacity {W}
  10.0,                    !- Maximum Outdoor Dry-bulb Temperature for Crankcase Heater
                           !- Operation {C}
  NaturalGas,              !- Fuel type
  4,                       !- Number of speeds
  7500,                    !- Rated Total Cooling Capacity, Speed 1 (gross) {W}
  0.75,                    !- Rated SHR, Speed 1
  3.0,                     !- Rated COP, Speed 1
  0.40,                    !- Rated Air Volume Flow Rate, Speed 1 {m3/s}
  HPACCoolCapFT Speed 1,   !- Total Cooling Capacity Modifier Curve, Speed 1 (temperature)
  HPACCoolCapFF Speed 1,   !- Total Cooling Capacity Modifier Curve, Speed 1 (flow fraction)
  HPACCOOLEIRFT Speed 1,   !- Energy Input Ratio Modifier Curve, Speed 1 (temperature)
  HPACCOOLEIRFF Speed 1,   !- Energy Input Ratio Modifier Curve, Speed 1 (flow fraction)
  HPACCOOLPLFFPLR Speed 1, !- Part Load Fraction Correlation, Speed 1 (part load ratio)
  1000.0,                  !- Nominal Time for Condensate Removal to Begin, Speed 1 {s}
  1.5,                     !- Ratio of Initial Moisture Evaporation Rate and Steady-state Latent
```

```
                             !- Capacity, Speed 1 {dimensionless}
    3.0,                     !- Maximum ON/OFF Cycling Rate, Speed 1 {cycles/hr}
    45.0,                    !- Latent Capacity Time Constant, Speed 1 {s}
    0.2,                     !- Rated waste heat fraction of power input, Speed 1 {dimensionless}
    HAPCCoolWHFT Speed 1,    !- Waste heat modifier curve, Speed 1 (temperature)
    0.9,                     !- Evaporative Condenser Effectiveness, Speed 1 {dimensionless}
    0.05,                    !- Evaporative Condenser Air Volume Flow Rate, Speed 1 {m3/s}
    50,                      !- Evaporative Condenser Pump Rated Power Consumption, Speed 1 {W}
    17500,                   !- Rated Total Cooling Capacity, Speed 2 (gross) {W}
    0.75,                    !- Rated SHR, Speed 2
    3.0,                     !- Rated COP, Speed 2
    0.85,                    !- Rated Air Volume Flow Rate, Speed 2 {m3/s}
    HPACCoolCapFT Speed 2,   !- Total Cooling Capacity Modifier Curve, Speed 2 (temperature)
    HPACCoolCapFF Speed 2,   !- Total Cooling Capacity Modifier Curve, Speed 2 (flow fraction)
    HPACCOOLEIRFT Speed 2,   !- Energy Input Ratio Modifier Curve, Speed 2 (temperature)
    HPACCOOLEIRFF Speed 2,   !- Energy Input Ratio Modifier Curve, Speed 2 (flow fraction)
    HPACCOOLPLFFPLR Speed 1, !- Part Load Fraction Correlation, Speed 2 (part load ratio)
    1000.0,                  !- Nominal Time for Condensate Removal to Begin, Speed 2 {s}
    1.5,                     !- Ratio of Initial Moisture Evaporation Rate and Steady-state Latent
                             !- Capacity, Speed 2 {dimensionless}
    3.0,                     !- Maximum ON/OFF Cycling Rate, Speed 2 {cycles/hr}
    45.0,                    !- Latent Capacity Time Constant, Speed 2 {s}
    0.2,                     !- Rated waste heat fraction of power input, Speed 2 {dimensionless}
    HAPCCoolWHFT Speed 2,    !- Waste heat modifier curve, Speed 2 (temperature)
    0.9,                     !- Evaporative Condenser Effectiveness, Speed 2 {dimensionless}
    0.1,                     !- Evaporative Condenser Air Volume Flow Rate, Speed 2 {m3/s}
    60,                      !- Evaporative Condenser Pump Rated Power Consumption, Speed 2 {W}
    25500,                   !- Rated Total Cooling Capacity, Speed 3 (gross) {W}
    0.75,                    !- Rated SHR, Speed 3
    3.0,                     !- Rated COP, Speed 3
    1.25,                    !- Rated Air Volume Flow Rate, Speed 3 {m3/s}
    HPACCoolCapFT Speed 3,   !- Total Cooling Capacity Modifier Curve, Speed 3 (temperature)
    HPACCoolCapFF Speed 3,   !- Total Cooling Capacity Modifier Curve, Speed 3 (flow fraction)
    HPACCOOLEIRFT Speed 3,   !- Energy Input Ratio Modifier Curve, Speed 3 (temperature)
    HPACCOOLEIRFF Speed 3,   !- Energy Input Ratio Modifier Curve, Speed 3 (flow fraction)
    HPACCOOLPLFFPLR Speed 1, !- Part Load Fraction Correlation, Speed 3 (part load ratio)
    1000.0,                  !- Nominal Time for Condensate Removal to Begin, Speed 3 {s}
    1.5,                     !- Ratio of Initial Moisture Evaporation Rate and Steady-state Latent
                             !- Capacity, Speed 3 {dimensionless}
    3.0,                     !- Maximum ON/OFF Cycling Rate, Speed 3 {cycles/hr}
    45.0,                    !- Latent Capacity Time Constant, Speed 3 {s}
    0.2,                     !- Rated waste heat fraction of power input, Speed 3 {dimensionless}
    HAPCCoolWHFT Speed 3,    !- Waste heat modifier curve, Speed 3 (temperature)
    0.9,                     !- Evaporative Condenser Effectiveness, Speed 3 {dimensionless}
    0.2,                     !- Evaporative Condenser Air Volume Flow Rate, Speed 3 {m3/s}
    80,                      !- Evaporative Condenser Pump Rated Power Consumption, Speed 3 {W}
    35500,                   !- Rated Total Cooling Capacity, Speed 4 (gross) {W}
    0.75,                    !- Rated SHR, Speed 4
    3.0,                     !- Rated COP, Speed 4
    1.75,                    !- Rated Air Volume Flow Rate, Speed 4 {m3/s}
    HPACCoolCapFT Speed 4,   !- Total Cooling Capacity Modifier Curve, Speed 4 (temperature)
    HPACCoolCapFF Speed 4,   !- Total Cooling Capacity Modifier Curve, Speed 4 (flow fraction)
    HPACCOOLEIRFT Speed 4,   !- Energy Input Ratio Modifier Curve, Speed 4 (temperature)
    HPACCOOLEIRFF Speed 4,   !- Energy Input Ratio Modifier Curve, Speed 4 (flow fraction)
    HPACCOOLPLFFPLR Speed 1, !- Part Load Fraction Correlation, Speed 4 (part load ratio)
    1000.0,                  !- Nominal Time for Condensate Removal to Begin, Speed 4 {s}
    1.5,                     !- Ratio of Initial Moisture Evaporation Rate and Steady-state Latent
                             !- Capacity, Speed 4 {dimensionless}
    3.0,                     !- Maximum ON/OFF Cycling Rate, Speed 4 {cycles/hr}
    45.0,                    !- Latent Capacity Time Constant, Speed 4 {s}
    0.2,                     !- Rated waste heat fraction of power input, Speed 4 {dimensionless}
    HAPCCoolWHFT Speed 4,    !- Waste heat modifier curve, Speed 4 (temperature)
    0.9,                     !- Evaporative Condenser Effectiveness, Speed 4 {dimensionless}
    0.3,                     !- Evaporative Condenser Air Volume Flow Rate, Speed 4 {m3/s}
    100;                     !- Evaporative Condenser Pump Rated Power Consumption, Speed 4 {W}

  COIL:Gas:Heating,
    Supp Gas Heating Coil 1,  !- Coil Name
    FanAndCoilAvailSched,    !- Available Schedule
    0.8,                     !- Gas Burner Efficiency of the Coil
    45000,                   !- Nominal Capacity of the Coil {W}
```

```
  SuppHeating Coil Air Inlet Node,  !- Coil_Air_Inlet_Node
  Air Loop Outlet Node;    !- Coil_Air_Outlet_Node

FAN:SIMPLE:ONOFF,
  Supply Fan 1,            !- Fan Name
  FanAndCoilAvailSched,    !- Available Schedule
  0.7,                     !- Fan Total Efficiency
  300.0,                   !- Delta Pressure {Pa}
  1.7,                     !- Max Flow Rate {m3/s}
  0.9,                     !- Motor Efficiency
  1.0,                     !- Motor In Airstream Fraction
  Mixed Air Node,          !- Fan_Inlet_Node
  DX Cooling Coil Air Inlet Node;  !- Fan_Outlet_Node

 DIRECT AIR,
   Zone1DirectAir,                 ! direct air unit name
   FanAndCoilAvailSched,           ! schedule name for on/off schedule
   Zone 1 Inlet Node,              ! zone supply air node name
   0.612;                          ! maximum air flow rate, m3/s

 DIRECT AIR,
   Zone2DirectAir,                 ! direct air unit name
   FanAndCoilAvailSched,           ! schedule name for on/off schedule
   Zone 2 Inlet Node,              ! zone supply air node name
   0.476;                          ! maximum air flow rate, m3/s

 DIRECT AIR,
   Zone3DirectAir,                 ! direct air unit name
   FanAndCoilAvailSched,           ! schedule name for on/off schedule
   Zone 3 Inlet Node,              ! zone supply air node name
   0.612;                          ! maximum air flow rate, m3/s
```

UnitarySystem:MultiSpeedHeatPump:AirToAir Outputs

```
HVAC,Average,Unitary MSHP Fan Part-Load Ratio
HVAC,Average,Unitary MSHP Compressor Part-Load Ratio
HVAC,Average,Unitary MSHP DX Coil Cycling Ratio
HVAC,Average,Unitary MSHP DX Coil Speed Ratio
HVAC,Average,Unitary MSHP DX Coil Speed Number
HVAC,Average,Unitary MSHP Electric Power[W]
HVAC,Sum,Unitary MSHP Electricity Energy Consumption[J]
HVAC,Average,Unitary MSHP Total Cooling Energy Rate [W]
HVAC,Average,Unitary MSHP Total Heating Energy Rate [W]
HVAC,Average,Unitary MSHP Sensible Cooling Energy Rate [W]
HVAC,Average,Unitary MSHP Sensible Heating Energy Rate [W]
HVAC,Average,Unitary MSHP Latent Cooling Energy Rate [W]
HVAC,Average,Unitary MSHP Latent Heating Energy Rate [W]
HVAC,Average,Unitary MSHP Auxiliary Electric Power[W]
HVAC,Sum,Unitary MSHP Auxiliary Electric Cooling Consumption[J]
HVAC,Sum,Unitary MSHP Auxiliary Electric Heating Consumption[J]
If heat recovery is specified:
HVAC,Average, Unitary MSHP Waste Heat Recovery Rate[W]
HVAC,Average, Unitary MSHP Waste Heat Recovery Inlet Temp[C]
HVAC,Average, Unitary MSHP Waste Heat Recovery Outlet Temp[C]
HVAC,Average, Unitary MSHP Waste Heat Recovery Mass Flow Rate[kg/s]
HVAC,Sum, Unitary MSHP Waste Heat Recovery Energy[J]
```

Unitary MSHP Fan Part-Load Ratio

This output variable is the ratio of actual air mass flow rate through the multispeed heat pump to the heat pump's design air mass flow rate (i.e., design volumetric flow rate converted to dry air mass flow rate) at Speed 1. For continuous fan operation mode, this variable is always 1.0 when the heat pump is available (based on the availability schedule). For cycling fan/cycling coil operation mode, the actual air mass flow rate is calculated based on the ratio of the sensible heating (or cooling) load to the steady-state heat pump heating (or cooling) capacity. For the cycling fan mode, the runtime fraction for the heat pump fan may be different from the fan part-load ratio reported here due the part-load performance of the heat pump's heating (or cooling) coil (delay at start-up to reach steady-state output). In general, runtime fractions are reported by individual components where appropriate (e.g., Fan:Simple:OnOff). When the speed number is greater than 1, the value is 1.0.

Unitary MSHP Compressor Part-Load Ratio

This output variable is the ratio of the sensible load (heating or cooling) to the steady-state capacity of the multispeed heat pump's DX heating or cooling coil at Speed 1. The runtime fraction for the heat pump compressor may be different from the compressor part-load ratio reported here due the part-load performance of the heating/cooling coil (delay at start-up to reach steady-state output). In general, runtime fractions are reported by individual components where appropriate. When the speed number is greater than 1, the value is 1.0.

Unitary MSHP DX Coil Cycling Ratio

This output variable is the ratio of the sensible load (heating or cooling) to the steady-state capacity of the multispeed heat pump's DX heating or cooling coil (Speed 1) for the entire system time step. The value is between 0.0 and 1.0 when the heat pump is cycling on and off its lowest speed (Speed 1) and 1.0 when the multispeed heat pump operates at speeds above 1.

Unitary MSHP DX Coil Speed Ratio

This output variable is the ratio of time in a system time step that the compressor is at rated speed between two consecutive speed numbers ([Compressor Speed - Compressor speed at Speed i-1] / [Compressor speed at Speed i - Compressor speed at Speed i-1]). The compressor speed ratio reports (1.0 is max, 0.0 is min) and any value in between as it is averaged over the time step. The value is 0.0 during Speed 1 operation.

The physical meaning of the speed ratio is dependent on the compressor configuration defined in the field of child coil object: Apply Part Load Fraction to Speeds greater than 1. The allowed choice is either Yes or No. When No is entered, one compressor is assumed for all speeds. The speed ratio represents how long the higher speed runs as a fraction of the system time step, and the lower speed runs in the rest of the system time step. When Yes is entered, multiple compressors are assumed, and each compressor has associated speed. The speed ratio represents how long the higher speed runs as a fraction of the system time step, and the low speed runs in a whole system time step.

Unitary MSHP DX Coil Speed Number

This output variable reports the maximum speed needed when the heat pump operates to meet the sensible load (heating or cooling) in a system time step. When the value is 1, the heat pump operates at Speed 1 (lowest speed). For this case the cycling ratio is between 0.0 and 1.0, while the speed ratio is 0.0. When the speed number output variable is above one, such as i, the heat pump operation is determined by the speed ratio through linear interpolation. For example, when the speed ratio is 0.4 and the speed number is 3, the heat pump operates at Speed 3 for 40% of a system time step and at Speed 2 for 60% of a system time step for a single compressor. For multiple compressors, the heat pump operates at Speed 3 in the 40% of a system time step and at Speed 2 in the whole system time step.

Unitary MSHP Total Heating Energy Rate [W]

This output field is the total (enthalpy) heat addition rate of the multispeed heat pump to the zones it is serving in Watts. This value is calculated using the enthalpy difference of the heat pump outlet air and inlet air streams, and the air mass flow rate through the heat pump. This value is calculated for each HVAC system time step being simulated, and the results (enthalpy addition only) are averaged for the time step being reported.

Unitary MSHP Total Cooling Energy Rate [W]

This output field is the total (enthalpy) heat extraction rate of the multispeed heat pump from the zones it is serving in Watts. This value is calculated using the enthalpy difference of the heat pump outlet air and inlet air streams, and the air mass flow rate through the heat pump. This value is calculated for each HVAC system time step being simulated, and the results (enthalpy extraction only) are averaged for the time step being reported.

Unitary MSHP Sensible Heating Energy Rate [W]

This output field reports the sensible heat addition rate of the multispeed heat pump to the zones it is serving in Watts. This value is calculated using the enthalpy difference of the heat pump outlet air and inlet air streams at a constant humidity ratio, and the air mass flow rate through the heat pump. This value is calculated for each HVAC system time step being simulated, and the results (heating only) are averaged for the time step being reported.

Unitary MSHP Sensible Cooling Energy Rate [W]

This output field reports the moist air sensible heat extraction rate of the multispeed heat pump from the zones it is serving in Watts. This value is calculated using the enthalpy difference of the heat pump outlet air and inlet air streams at a constant humidity ratio, and the air mass flow rate through the heat pump. This value is calculated for each HVAC system time step being simulated, and the results (cooling only) are averaged for the time step being reported.

Unitary MSHP Latent Heating Energy Rate [W]

This output field is the latent heat addition (humidification) rate of the multispeed heat pump in Watts. This value is calculated as the difference between the total energy rate and the sensible energy rate provided by the multispeed heat pump. This value is calculated for each HVAC system time step being simulated, and the results (latent heat addition only) are averaged for the time step being reported.

Unitary MSHP Latent Cooling Energy Rate [W]

This output field is the latent heat extraction (dehumidification) rate of the multispeed heat pump in Watts. This value is calculated as the difference between the total energy rate and the sensible energy rate provided by the multispeed heat pump. This value is calculated for each HVAC system time step being simulated, and the results (latent heat extraction only) are averaged for the time step being reported.

Unitary MSHP Electric Power [W]

This output field is the electricity consumption rate of the multispeed heat pump in Watts. The consumption includes electricity used by the DX coils (including crankcase heater if the fuel type is electricity), fans (indoor supply air fan and the condenser fans associated with the DX coil[s]), auxiliary power during on and off period, and the supplemental heating coil (if electric). This value is calculated for each HVAC system time step being simulated, and the results are averaged for the time step being reported. Any non-electric energy use is not reported by the heat pump object but is reported in the associated coil objects as appropriate.

Unitary MSHP Electric Consumption [J]

This output field is the electricity consumption of the multispeed heat pump in Joules for the time step being reported. The consumption includes electricity used by the DX compressor (including crankcase heater if the fuel type is electricity), fans (indoor supply air fan and the condenser fans associated with the DX coil[s]), auxiliary power during on and off period, and the supplemental heating coil (if electric). This value is calculated for each HVAC system time step being simulated, and the results are summed for the time step being reported. Any non-electric energy use is not reported by the heat pump object but is reported in the associated coil objects as appropriate.

Unitary MSHP Auxiliary Electric Power [W]

This output field is the average auxiliary electricity consumption rate (including both on-cycle and off-cycle) in Watts for the time step being reported.

Unitary MSHP Auxiliary Electric Cooling Consumption [J]

This is the auxiliary electricity consumption in Joules for the time step being reported. This is the auxiliary electricity consumption during periods when the heat pump is providing cooling (DX cooling coil is operating). This output is also added to a report meter with Resource Type = Electricity, End Use Key =Cooling, Group Key = System (ref. Report Meter).

Unitary MSHP Auxiliary Electric Heating Consumption [J]

This is the auxiliary electricity consumption in Joules for the time step being reported. This is the auxiliary electricity consumption during periods when the heat pump is providing heating (DX heating coil is operating). This output is also added to a report meter with Resource Type = Electricity, End Use Key =Heating, Group Key = System (ref. Report Meter).

Unitary MSHP Waste Heat Recovery Inlet Temp [C]

Unitary MSHP Waste Heat Recovery Outlet Temp [C]

Unitary MSHP Waste Heat Recovery Mass Flow Rate [kg/s]

These outputs are the heat recovery inlet and outlet temperatures and water mass flow rate for multispeed heat pumps with heat recovery.

Unitary MSHP Waste Heat Recovery Rate [W]

Unitary MSHP Waste Heat Recovery Energy [J]

For multispeed heat pumps with heat recovery, these outputs are the recoverable energy rate (in Watts) and energy (in Joules).

Engineering Document for UnitarySystem:MultiSpeedHeatPump:AirToAir

Overview

The multispeed air-to-air heat pump is a “virtual” component that consists of an on/off or constant volume fan component, a multispeed DX cooling coil, a multispeed DX heating coil, and a gas or electric supplemental heating coil. The main difference between this heat pump object and other EnergyPlus heat pump objects is that this object allows from two to four discrete compressor speeds for heating and cooling operation (instead of a single speed for each mode). The specific configuration of the blow through heat pump is shown in the following figure. For a draw through heat pump, the fan is located between the DX heating coil and the supplemental heating coil.

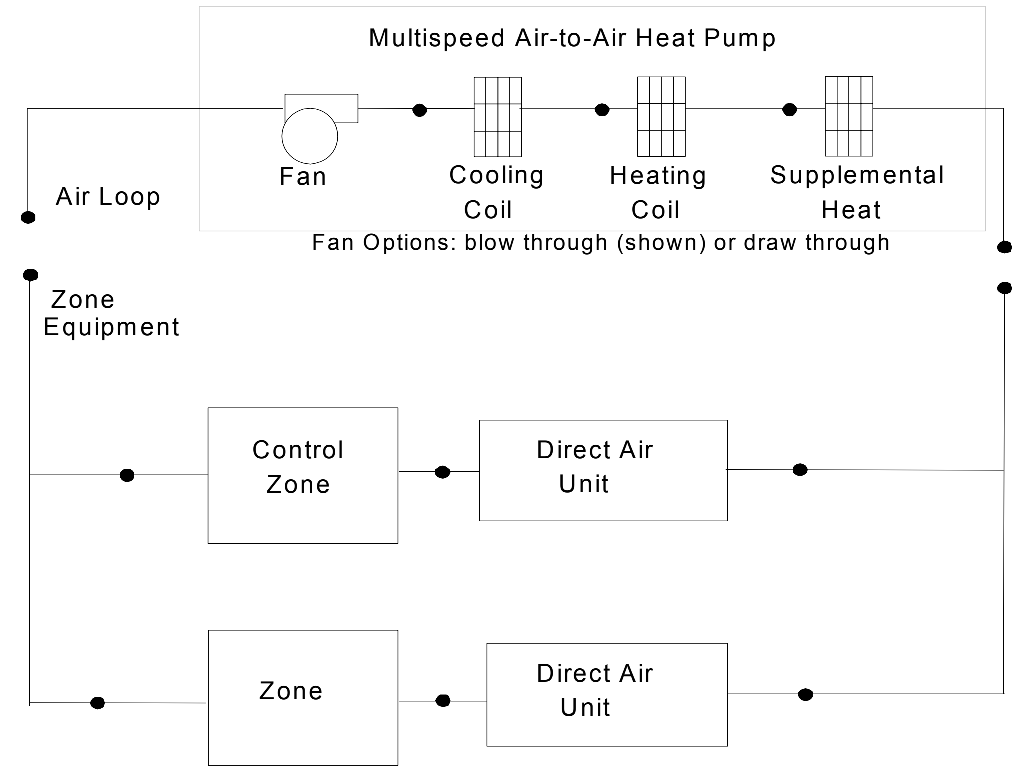


Figure 4. Schematic of a Multispeed Air-to-Air Heat Pump (Blow-through Configuration)

While the heat pump may be configured to serve multiple zones, system operation is controlled by a thermostat located in a single "control" zone. One of the key input parameters for the heat pump component is the fraction of the total system volumetric airflow that goes through the controlling zone. The heat pump module scales the calculated load for the control zone upward based on this fraction to determine the total load to be met by the heat pump. The module then proceeds to calculate the required cycling ratio, speed ratio and speed number for the system coil and determines the supply air mass flow rate to meet this total load based on the speed number. The cycling ratio is the ratio of the sensible load (heating or cooling) to the steady-state capacity of the multispeed heat pump's DX heating or cooling coil at Speed 1 for the entire system time step. It is equivalent to the part load ratio for a single speed DX coil. The value is between 0.0 and 1.0 when the system operates at its lowest speed (Speed 1) and 1.0 when the multispeed heat pump operates at speeds above 1. The speed ratio is the ratio of time in a system time step that the compressor is at rated speed between two consecutive speed numbers ([Compressor Speed - Compressor speed at Speed i-1] / [Compressor speed at Speed i - Compressor speed at Speed i-1]). The compressor speed ratio is between 0.0 and 1.0 when the speed number is above 1 and is 0.0 during Speed 1 operation. The speed number is the lowest index number whose corresponding full-load sensible capacity at the given air mass flow rate is greater than or equal to the sensible load (heating or cooling) in a system time step. The heating or cooling capacity delivered by the heat pump is distributed to all of the zones served by this system via the direct air units that supply air to each zone.

The heat pump component is able to model supply air fan operation in two modes: cycling fan – cycling coil (i.e., AUTO fan) and continuous fan – cycling coil (i.e., fan ON). Fan:Simple:OnOff must be used to model AUTO fan, while Fan:Simple:OnOff or Fan:Simple:ConstVolume can be used to model fan ON. The fan operation mode is specified using a supply air fan operating mode schedule where schedule values of 0 denote cycling fan operation and schedule values other than 0 (a 1 is usually used) denote continuous fan operation. Using this schedule, the supply air fan may be cycled with cooling or heating coil operation or operated continuously based on time of day (e.g. cycling fan operation at night and continuous fan operation during the day). The fan operating mode schedule specified here overrides the Supply Air Fan Mode Operation input in the DX coil objects (Ref. Coil:DX:MultiSpeed:Cooling and Coil:DX:MultiSpeed:Heating).

Several output variables are reported by the heat pump object including fan part-load ratio, compressor part-load ratio, cycling ratio, speed ratio and speed number. Fan part-load ratio is defined as the actual air mass flow rate through the system for the time step divided by the operating supply air mass flow rate specified for the heat pump ($\dot{m}_{actual} / \dot{m}_{ON}$) at speed 1. Fan part-load ratio is set to 1.0 when the heat pump operates at speeds above 1. The operating supply air mass flow rate may be different for cooling, heating, and when no cooling or heating is required. Compressor part-load ratio is the actual load for the time step divided by the full-load sensible capacity (see Eqn. (3) or Eqn. (7)). If the defrost strategy is reverse cycle for a DX heating coil, the compressor part-load ratio is the sum of the actual load and the defrost load divided by the full-load sensible capacity. Therefore, the compressor part load ratio for the DX heating coil may be greater than the cycling ratio. This heat pump object also reports the sensible, latent and total cooling and heating rate, as well as the electricity consumption for the unit with separate accounting of auxiliary electric consumption. Furthermore, five report variables related to waste heat recovery are available if the user chooses to model this option.

Model Description

As described previously, the heat pump is a "virtual" component consisting of a fan, multispeed DX cooling coil, multispeed DX heating coil and supplemental heating coil. The sole purpose of the heat pump model is to properly coordinate the operation of the various system components. The following sections describe the flow of information within the model, as well as the differences between cycling and continuous supply air fan operation.

Cooling Operation

The description of heat pump cooling operation is divided in two sections: sensible capacity and average supply air flow rate. Actually, the determinations of capacity and supply air flow rate are related, so these calculates are performed in unison.

Capacity calculation

If EnergyPlus determines that the heat pump must supply cooling to the control zone to meet the zone air temperature set point, then the heat pump model computes the total sensible cooling load (negative) to be delivered to the zones being served based on the control zone sensible cooling load and the fraction of the heat pump air flow that goes through the control zone.

$$Heat\,Pump\,Cooling\,Load = \frac{Control\,Zone\,Cooling\,Load}{Control\,Zone\,Air\,Flow\,Fraction} \tag{1}$$

The model then calculates the heat pump's sensible cooling energy rate delivered to the zones being served when the system runs at full-load conditions at the highest speed and when the DX cooling coil is OFF. If the supply air fan cycles with the compressor, then the sensible cooling energy rate is zero when the cooling coil is OFF. However if the fan is scheduled to run continuously regardless of coil operation, then the sensible cooling energy rate will not be zero when the cooling coil is OFF.

Calculating the sensible cooling energy rate involves modeling the supply air fan (and associated fan heat) and the multispeed DX cooling coil. The multispeed DX heating coil and the supplemental heating coil are also modeled, but only to pass the air properties and mass flow rate from their inlet nodes to their outlet nodes. For each of these cases (full load at highest cooling speed and DX cooling coil OFF), the sensible cooling energy rate delivered by the heat pump is calculated as follows:

$$FullCoolOutput_{Highest\,Speed} = (\dot{m}_{HighestSpeed})(h_{out,\,full\,load} - h_{control\,zone})_{HR\min}$$
$$NoCoolOutput_{Highest\,Speed} = (\dot{m}_{CoilOff})(h_{out,\,full\,load} - h_{control\,zone})_{HR\min} \quad (2)$$

where:

$\dot{m}_{HighestSpeed}$ = air mass flow rate through heat pump at the highest cooling speed [kg/s]

$h_{out,\,full\,load}$ = enthalpy of air exiting the heat pump at full-load conditions [J/kg]

$h_{control\ zone}$ = enthalpy of air leaving the control zone (where thermostat is located) [J/kg]

HR_{min} = the minimum humidity ratio of the heat pump exiting air or the air leaving the control zone [kg/kg]

$\dot{m}_{CoilOff}$ = air mass flow rate through the heat pump with the cooling coil OFF [kg/s]

$h_{out,coil\ off}$ = enthalpy of air exiting the heat pump with the cooling coil OFF [J/kg]

If the heat pump's sensible cooling rate at the highest speed (full load, no cycling) is insufficient to meet the entire cooling load, the controlled zone conditions will not be met. The reported cycling rate and speed ratio are 1, and the speed number is set to the highest index number. If the total sensible cooling load to be met by the system is less than the sensible cooling rate at the highest speed, then the following steps are performed.

1. Calculate the sensible cooling energy rate at Speed 1

$$FullCoolOutput_{Speed1} = (\dot{m}_{Speed1})(h_{out,\,full\,load} - h_{control\,zone})_{HR\min}$$

where:

$\dot{m}_{Speed1}$ = air mass flow rate through heat pump at Speed 1 [kg/s]

2. If the sensible cooling energy rate delivered by the heat pump at Speed 1 is greater or equal to the sensible load, the cycling ratio (part-load ratio) for the heat pump is estimated.

$$CyclingRatio = \frac{ABS(HeatingCoilSensibleLoad)}{FullHeatingCoilCapacity}$$
$$= MAX\left(0.0, \frac{ABS(Heat\ Pump\ Heating\ Load - AddedFanHeat)}{ABS(FullHeatOutput_{Speed1} - AddedFanHeat_{Speed1})}\right) \quad (3)$$

where:

AddedFanHeat = generated supply air fan heat, which is a function of part load ratio and as internal component cooling load [W].

$AddedFanHeat_{Speed1}$ = generated supply air fan heat at Speed 1 (part load ratio=1) [W].

Since the part-load performance of the DX cooling coil is frequently non-linear,and the supply air fan heat varies based on cooling coil operation for the case of cycling fan/cycling coil (AUTO fan), the final part-load ratio for the cooling coil compressor and fan are determined through iterative calculations (successive modeling of the cooling coil and fan) until the heat pump's cooling output matches the cooling load to be met within the convergence tolerance. The convergence tolerance is fixed at 0.001 and is calculated based on the difference between the load to be met and the heat pump's cooling output divided by the load to be met.

$$Tolerance = \frac{Heat\ Pump\ Cooling\ Load - HeatPumpOutput_{Cycling}}{Heat\ Pump\ Cooling\ Load} = 0.001$$

where:

$HeatPumpOutput_{Cycling}$ = heat pump delivered sensible capacity for Speed 1 operating at a specific cycling ratio (W)

$$HeatPumpOutput_{Cycling} = \dot{m}_{HeatPump}(h_{out} - h_{control,zone})_{HR\min}$$

where:

$\dot{m}_{HeatPump}$ = average air mass flow rate defined in the next section [kg/s]

$h_{out,}$ = enthalpy of air exiting the heat pump at part load conditions [J/kg]

For this case where speed 1 operation was able to meet the required cooling load, the speed ratio is set to zero and speed number is equal to 1.

3. If the heat pump's cooling output at full load for Speed 1 is insufficient to meet the entire cooling load, the Cycling ratio is set equal to 1.0 (compressor and fan are not cycling). Then the cooling speed is increased and the delivered sensible capacity is calculated. If the full load sensible capacity at Speed n is greater than or equal to the sensible load, the speed ratio for the heat pump is estimated:

$$Speed\,Ratio = \frac{ABS(HeatPumpCooling\,Load - AddeFanHeat - FullCoolOutput_{Speed\,n-1})}{ABS(FullCoolOutput_{Speed\,n} - FullCoolOutput_{Speed\,n-1})}$$

Although a linear relationship is assumed by applying the speed ratio to obtain the effective capacity and mass flow rate between speed n and n-1, the outlet air node conditions are dependent on the combined outputs and may not be linear. In addition, the supply air fan heat varies with the speed ratio due to different supply mass flow rates between speed n and n-1. Therefore, the final speed ratio for the cooling coil compressor and fan are determined through iterative calculations (successive modeling of the cooling coil and fan) until the heat pump's cooling output matches the cooling load to be met within the convergence tolerance. The convergence tolerance is fixed at 0.001 and is calculated based on the difference between the load to be met and the heat pump's cooling output divided by the load to be met.

$$Tolerance = \frac{Heat\ Pump\ Cooling\ Load - HeatPumpOutput_{SpeedRatio}}{Heat\ Pump\ Cooling\ Load} = 0.001$$

where:

$HeatPumpOutput_{Speed,n}$= heat pump delivered sensible capacity between two consecutive speeds at a specific speed ratio (W)

$$HeatPumpOutput_{SpeedRatio} = (SpeedRatio)FullCoolOutput_{Speed\ n}$$
$$= (1 - SpeedRatio)FullCoolOutput_{Speed\ n-1} - AddedFanHeat_{SpeedRatio}$$

where:

$AddedFanHeat_{SpeedRatio}$ = generated supply air fan heat at a specific speed ratio [W]

In this case, the reported cycling ratio is 1 and speed number is equal to n.

Air Mass Flow Rate Calculation

Speed 1 operation

If the heat pump has been specified with cycling fan/cycling coil (AUTO fan), then the heat pump's operating supply air mass flow rate is determined by the cycling ratio (PartLoadRatio) for Speed 1. The supply air mass flow rate is multiplied by the cycling ratio to determine the average air mass flow rate for the system simulation time step. The air conditions at nodes downstream of the cooling coils represent the full-load (steady-state) values when the coil is operating.

$$\dot{m}_{HeatPump} = (CyclingRatio)\dot{m}_{Speed1}$$

If the fan operates continuously (i.e., when the supply air fan operating mode schedule values are NOT equal to 0), the operating air mass flow rate through the heat pump is calculated as the average of the user-specified air flow rate when the heat pump cooling coil is ON at Speed 1 and the user-specified air flow rate when the heat pump cooling coil is OFF (user-specified supply air volumetric flow rates converted to dry air mass flow rates).

$$\dot{m}_{HeatPump} = (CyclingRatio)\dot{m}_{Speed1} + (1.0 - CyclingRatio)\dot{m}_{CoilOff}$$

where:

$\dot{m}_{HeatPump}$ = average air mass flow rate through heat pump [kg/s]

$\dot{m}_{Speed1}$ = air mass flow rate through heat pump when cooling coil is ON at Speed 1 [kg/s]

$\dot{m}_{CoilOFF}$ = air mass flow rate through heat pump when no heating or cooling is needed [kg/s]

In this case, the air conditions at nodes downstream of the cooling coils are calculated as the average conditions over the simulation time step (i.e., the weighted average of full-load conditions when the coil is operating and inlet air conditions when the coil is OFF).

Higher Speed Operation

When the heat pump operates at higher speeds to meet the required cooling load, the supply air mass flow rate is linearly interpolated between two consecutive speeds:

$$\dot{m}_{HeatPump} = (SpeedRatio)\dot{m}_{Speed\,n} + (1.0 - SpeedRatio)\dot{m}_{Speed\,n-1}$$

where:

$\dot{m}_{HeatPump}$ = average air mass flow rate through the heat pump for the time step [kg/s]

$\dot{m}_{Speed\,n}$ = air mass flow rate through heat pump when cooling coil is ON at Speed n [kg/s]

$\dot{m}_{Speed\,n-1}$ = air mass flow rate through heat pump when cooling coil is ON at Speed n-1 [kg/s]

For this case of higher speed operation, the air conditions at nodes downstream of the cooling coils are determined by the delivered cooling capacity and supply air mass flow rates between two consecutive speeds.

Although the above sections present the capacity and air mass flow rate calculation separately, they are dependent and change every iteration until convergence is reached for the time step being simulated.

Heating Operation

The description of heat pump heating operation is divided in two sections: total (sensible) capacity and average supply air flow rate. Actually, the determinations of capacity and supply air flow rate are related, so these calculates are performed in unison.

Capacity calculation

If EnergyPlus determines that the heat pump must supply cooling to the control zone to meet the zone air temperature set point, then the heat pump model computes the total sensible cooling load (positive) to be delivered to the zones being served based on the control zone sensible cooling load and the fraction of the heat pump air flow that goes through the control zone.

$$Heat\ Pump\ Heating\ Load = \frac{Control\ Zone\ Heating\ Load}{Control\ Zone\ Air\ Flow\ Fraction} \tag{4}$$

The model then calculates the heat pump's sensible heating energy rate delivered to the zones being served when the system runs at full-load conditions at the highest speed and when the DX heating coil is OFF (without supplemental heater operation in either case). If the supply air fan cycles with the compressor, then the sensible heating energy rate is zero when the compressor is OFF. However if the fan is scheduled to run continuously regardless of coil operation, then the sensible heating energy rate will not be zero when the compressor is OFF. Calculating the sensible heating energy rate involves modeling the supply air fan (and associated fan heat), the DX cooling coil (simply to pass the air properties and mass flow rate from its inlet node to its outlet node), the DX heating coil, and the supplemental heating coil (simply to pass the air properties and mass flow rate from its inlet node to its outlet node). For each of these cases (full load and DX heating coil OFF, without supplemental heater operation in either case), the sensible heating energy rate delivered by the heat pump is calculated as follows:

$$Full\,HeatOutput_{Highest\,Speed} = (\dot{m}_{Highest\,Speed})(h_{out,\,full\,load} - h_{control\,zone})_{HR\min} \tag{5}$$

$$NoHeatOutput_{Highest\,Speed} = (\dot{m}_{CoilOff})(h_{out,\,full\,load} - h_{control\,zone})_{HR\min} \tag{6}$$

where:

$\dot{m}_{HighestSpeed}$ = air mass flow rate through heat pump at the highest heating speed [kg/s]

$h_{out,\,full\,load}$ = enthalpy of air exiting the heat pump at full-load conditions [J/kg]

$h_{control\ zone}$ = enthalpy of air leaving the control zone (where thermostat is located) [J/kg]

HR_{min} = enthalpies evaluated at a constant humidity ratio, the minimum humidity ratio of the heat pump exiting air or the air leaving the control zone

$\dot{m}_{CoilOff}$ = air mass flow rate through the heat pump with the cooling coil OFF [kg/s]

$h_{out,coil\ off}$ = enthalpy of air exiting the heat pump with the cooling coil OFF [J/kg]

If the heat pump's DX heating coil output full load at the highest speed is insufficient to meet the entire heating load, the remaining heating load is passed to the supplemental heating coil. If the heat pump model determines that the outdoor air temperature is below the minimum outdoor air temperature for compressor operation (specified by the user), the compressor is turned off and the entire heating load is passed to the supplemental gas or electric heating coil. The heat pump exiting air conditions and energy consumption are calculated and reported by the individual component models (fan, DX heating coil, and supplemental gas or electric heating coil).

If the total heating load to be met by the system is less than the sensible heating rate at the highest speed, then the following steps are performed.

1. Calculate the sensible cooling energy rate at Speed 1

$$FullHeatOutput_{Speed1} = (\dot{m}_{Speed1})(h_{out,full\,load} - h_{control\,zone})_{HR\min}$$

where:

$\dot{m}_{Speed1}$ = air mass flow rate through heat pump at Speed 1 [kg/s]

2. If the sensible cooling energy rate delivered by the heat pump at Speed 1 is greater or equal to the sensible load, the cycling ratio (part-load ratio) for the heat pump is estimated.

$$CyclingRatio = \frac{ABS(HeatingCoilSensibleLoad)}{FullHeatingCoilCapacity}$$

$$= MAX\left(0.0, \frac{ABS(Heat\ Pump\ Heating\ Load - AddedFanHeat)}{ABS(FullHeatOutput_{Speed1} - AddedFanHeat_{Speed1})}\right) \quad (7)$$

where:

AddedFanHeat = generated supply air fan heat, which is a function of part load ratio and as internal component cooling load [W].

$AddedFanHeat_{Speed1}$= generated supply air fan heat at Speed 1 (part load ratio=1) [W].

Since the part-load performance of the DX heating coil is frequently non-linear (Ref: Coil Model – DX Heating Coil Model(HVAC)), and the supply air fan heat varies based on heating coil operation for the case of cycling fan/cycling coil (AUTO fan), the final part-load ratio for the heating coil compressor and fan are determined through iterative calculations (successive modeling of the heating coil and fan) until the heat pump's heating output matches the heating load to be met within the convergence tolerance. The convergence tolerance is fixed at 0.001 and is calculated based on the difference between the load to be met and the heat pump's heating output divided by the load to be met.

$$Tolerance = \frac{Heat\ Pump\ Heating\ Load - HeatPumpOutput_{Cycling}}{Heat\ Pump\ Heating\ Load} = 0.001$$

where:

$HeatPumpOutput_{Cycling}$= heat pump delivered sensible capacity for Speed 1 operating at a specific cycling ratio (W)

$$HeatPumpOutput_{Cycling} = \dot{m}_{HeatPump}(h_{out} - h_{control,zone})_{HR\min}$$

where:

$\dot{m}_{HeatPump}$ = average air mass flow rate defined in the next section [kg/s]

$h_{out,}$ = enthalpy of air exiting the heat pump at part load conditions [J/kg]

For this case where speed 1 operation was able to meet the required cooling load, the speed ratio is set to zero and speed number is equal to 1.

3. If the heat pump's heating output at full load for Speed 1 is insufficient to meet the entire cooling load, the Cycling ratio (PartLoadRatio) is set equal to 1.0 (compressor and fan are not cycling). Then the heating speed is increased and the delivered sensible capacity is calculated. If the full load sensible capacity at Speed n is greater than or equal to the sensible load, the speed ratio for the heat pump is estimated:

$$Speed\ Ratio = \frac{ABS\left(HeatPump\ Heating\ Load - AddedFanHeat - Full\ HeatOutput_{Speed\ n-1}\right)}{ABS\left(FullHeatOutput_{Speed\ n} - FullHeatOutput_{Speed\ n\text{-}1}\right)}$$

Although a linear relationship is assumed by applying the speed ratio to obtain the effective capacity and air mass flow rate between speed n and n-1, the outlet node conditions are dependent on the combined outputs and may not be linear. In addition, the supply air fan heat varies based on cooling coil operation for the case of cycling fan/cycling coil (AUTO fan). Therefore, the final speed ratio for the cooling coil compressor and fan are determined through iterative calculations (successive modeling of the cooling coil and fan) until the heat pump's cooling output matches the cooling load to be met within the convergence tolerance. The convergence tolerance is fixed at 0.001 and is calculated based on the difference between the load to be met and the heat pump's cooling output divided by the load to be met.

$$Tolerance = \frac{Heat\ Pump\ Cooling\ Load - HeatPumpOutput_{SpeedRatio}}{Heat\ Pump\ Cooling\ Load} = 0.001$$

where:

$HeatPumpOutput_{SpeedRatio}$= heat pump delivered sensible capacity between two consecutive speeds at a specific ratio [W]

$$\begin{aligned} HeatPumpOutput_{SpeedRatio} &= (SpeedRatio)FullHeatOutput_{Speed\ n} \\ &= (1 - SpeedRatio)FullHeatOutput_{Speed\ n-1} - AddedFanHeat_{SpeedRatio} \end{aligned}$$

where:

$AddedFanHeat_{SpeedRatio}$ = generated supply air fan heat at a specific speed ratio [W]

In this case, the reported cycling ratio is 1 and speed number is equal to n.

Air Mass Flow Rate Calculation

The air mass flow rate calculations during heating operation are the same as those described above for cooling operation.

Fan Placement

Supply air fan placement impacts the iteration strategy. When the fan placement type is blow through, the air mass flow rate and coil part load factor (PLF) affect the fan outlet conditions. Since the fan is upstream of the coil components with this fan placement, the fan outlet conditions are calculated without knowing the next component's performance at the beginning of each iteration. DX coil performance is strongly dependent on the inlet conditions, so without correct inlet conditions the DX coil components may not be simulated correctly. Therefore, the heat pump components are called twice for each iteration when fan placement is 'blow through'. The correct part load factor for the fan component is obtained after the first call, so that the more realistic fan outlet conditions are used to simulate the coil performance in the second call. This extra call to the heat pump components is not required for the draw through fan since the supply air fan is located downstream of the DX coils with this fan placement.

Waste Heat Calculation

When the heat recovery is active (the value of the Design Heat Recovery Water Flow Rate field is greater than 0), the outlet node temperature of heat recovery is calculated based on the recoverable waste heat generated by its child objects (Coil:DX:MultiSpeed:Cooling and Coil:DX:MultiSpeed:Heating):

$$T_{outlet} = T_{inlet} + \frac{Q_{WasteHeat}}{C_p \dot{m}_{hr}}$$

where:

T_{outlet}	= outlet node temperature of heat recovery, C
T_{inlet}	= inlet node temperature of heat recovery, C
$Q_{WasteHeat}$	= recoverable waste heat generated by its child objects, W
C_p	= inlet node temperature of heat recovery, C
$\dot{m}_{hr}$	= mass flow rate of heat recovery, kg/s

If the outlet node temperature is above the value of the Maximum Temp for Heat Recovery field, the outlet node temperature is reset to the value of Maximum Temp for Heat Recovery.

Input Output Reference for Coil:DX:MultiSpeed:Heating

This component models a DX heating unit with multiple discrete levels of heating capacity. Currently, this heating coil can only be referenced by a UnitarySystem:MultiSpeedHeatPump:AirToAir compound object. The multispeed DX heating coil can have from two to four operating speeds. When the coil operates at Speed 1 (the lowest speed), its performance is very similar to the Coil:DX:EmpiricalHeating object where the impacts of part-load ratio can be included. When the coil operates at higher speeds (above Speed 1), the linear approximation methodology is applied. The coil outputs at two consecutive speeds are linearly interpolated to meet the required heating capacity during an HVAC system time step. When the coil performs above the lowest speed, the user can chose if they want to include part-load ratio impacts at the higher speeds.

The multispeed unit is described by specifying the performance at different operating speeds. Each speed has its own set of input specifications: full load capacity, COP and air flow rate at rated conditions, along with modifier curves to determine performance when actual operating conditions are different from the rated conditions.

The coil operates to meet the sensible capacity being requested. When this requested capacity is above the sensible capacity of the highest operating speed, the coil runs continuously at the highest speed. When the requested capacity is between the sensible capacities of two consecutive speeds, the unit will operate a portion of the time at each speed to meet the request. When the requested capacity is less than the low speed (Speed 1) capacity, the unit will cycle on/off as needed.

After inputting the coil name, available schedule, and inlet and outlet air node names, the next input item for the multiSpeed DX heating coil is the supply air fan operation mode. Either the supply air fan runs continuously while the DX coil cycles on/off, or the fan and coil cycle on/off together. The next input defines the minimum outdoor dry-bulb temperature where the compressor will operate. The followed two inputs are related to crankcase heater operation: capacity and maximum outdoor dry-bulb temperature for crankcase heater operation. The next six inputs cover defrost operation: defrost EIR modifier curve, the maximum outdoor dry-bulb temperature for defrost operation, the type of defrost strategy (reverse-cycle or resistive), defrost control (timed or on-demand), the fractional defrost time period (timed defrost control only), and the resistive defrost heater capacity if a resistive defrost strategy is selected. The activation of defrost is dependent on outdoor conditions. The capacity reduction and energy use modification are independent of speed. The defrost EIR modifier is described below:

> The defrost energy input ratio (EIR) modifier curve (function of temperature) is a bi-quadratic curve with two independent variables: outdoor air dry-bulb temperature and the heating coil entering air wet-bulb temperature. The output of this curve is multiplied by the heating coil capacity, the fractional defrost time period and the runtime fraction of the heating coil to give the defrost power at the specific temperatures at which the coil is operating. This curve is only required when a reverse-cycle defrost strategy is specified.

The next input allows the user to choose whether to apply the part load fraction correlation to speeds greater than 1 or not. The following input is the type of fuel.

Then the number of speed for heating is entered. The rest of inputs are speed dependent. Each set of data consists of rated heating capacity, rated COP, and the rated air volume flow rate. These three inputs determine the coil performance at the rating point (outside air dry-bulb temperature of 8.33°C, outside air wet-bulb temperature of 6.11°C, coil entering air dry-bulb temperature of 21.11°C, coil entering air wet-bulb temperature of 15.55°C). The rated air volume flow rate should be between .00004027 m^3/s and .00006041 m^3/s per watt of rated total heating capacity. The rated waste heat fraction is needed to calculate how much waste heat is available at the rated conditions. In addition, up to 6 modifier curves are required per speed.

1) The total heating capacity modifier curve (function of temperature) can be a function of both the outdoor and indoor air dry-bulb temperature or only the outdoor air dry-bulb temperature. User has the choice of a bi-quadratic curve with two independent variables or a quadratic curve as well as a cubic curve with a single independent variable. The bi-quadratic curve is recommended if sufficient manufacturer data is available as it provides sensitivity to the indoor air dry-bulb temperature and a more realistic output. The output of this curve is multiplied by the rated total heating capacity to give the total heating capacity at specific temperature operating conditions (i.e., at an outdoor or indoor air temperature different from the rating point temperature).
2) The total heating capacity modifier curve (function of flow fraction) is a quadratic or cubic curve with the independent variable being the ratio of the actual air flow rate across the heating coil to the rated air flow rate (i.e., fraction of full load flow). The output of this curve is multiplied by the rated total heating capacity and the total heating capacity modifier curve (function

of temperature) to give the total heating capacity at the specific temperature and air flow conditions at which the coil is operating.

3) The energy input ratio (EIR) modifier curve (function of temperature) can be a function of both the outdoor and indoor air dry-bulb temperature or only the outdoor air dry-bulb temperature. User has the choice of a bi-quadratic curve with two independent variables or a quadratic curve as well as a cubic curve with a single independent variable. The bi-quadratic curve is recommended if sufficient manufacturer data is available as it provides sensitivity to the indoor air dry-bulb temperature and a more realistic output. The output of this curve is multiplied by the rated EIR (inverse of the rated COP) to give the EIR at specific temperature operating conditions (i.e., at an outdoor or indoor air temperature different from the rating point temperature).
4) The energy input ratio (EIR) modifier curve (function of flow fraction) is a quadratic or cubic curve with the independent variable being the ratio of the actual air flow rate across the heating coil to the rated air flow rate (i.e., fraction of full load flow). The output of this curve is multiplied by the rated EIR (inverse of the rated COP) and the EIR modifier curve (function of temperature) to give the EIR at the specific temperature and air flow conditions at which the coil is operating.
5) The part load fraction correlation (function of part load ratio) is a quadratic or cubic curve with the independent variable being part load ratio (sensible heating load / steady-state heating capacity). The output of this curve is used in combination with the rated EIR and EIR modifier curves to give the “effective” EIR for a given simulation time step. The part load fraction correlation accounts for efficiency losses due to compressor cycling.
6) The waste heat modifier curve (function of temperature) is a bi-quadratic curve with two independent variables: outdoor air dry-bulb temperature and the heating coil entering air dry-bulb temperature. The output of this curve is multiplied by the heating input energy, the waste heat fraction of heat input to give the recoverable waste heat.

The curves are simply specified by name. Curve inputs are described in the curve manager section of this document (ref. Performance Curves).

Field: Coil Name

This alpha field defines a unique user-assigned name for an instance of a multispeed DX heating coil. Any reference to this DX heating coil by another object will use this name. The only allowed parent is UnitarySystem:MultiSpeedHeatPump:AirToAir.

Field: Availability Schedule

This alpha field defines the name of the schedule (ref: Schedule) that denotes whether the multispeed DX heating coil can run during a given hour. A schedule value greater than 0 (usually 1 is used) indicates that the unit can be on during the hour. A value less than or equal to 0 (usually 0 is used) denotes that the unit must be off for the hour.

Field: Coil Air Inlet Node

This alpha field defines the name of the HVAC system node from which the DX heating coil draws its inlet air.

Field: Coil Air Outlet Node

This alpha field defines the name of the HVAC system node to which the DX heating coil sends its outlet air.

Field: Supply Air Fan Operation Mode

This alpha field has two choices: CycFanCycComp or ContFanCycComp. The first choice stands for “cycling fan cycling compressor”. This means that the unit unloads by cycling both the fan and compressor; that is, both the supply fan and the heating coil compressor cycle on and off together to meet the load. The second choice stands for “continuous fan cycling compressor”. The supply fan runs continuously while the heating coil compressor cycles. The parent object of UnitarySystem:MultiSpeedHeatPump:AirToAir has a field as a schedule to define fan operation mode at a given time. The value defined in the parent schedule will override the fan operation mode defined in this field.

Field: Minimum Outdoor Dry-bulb Temperature for Compressor Operation

This numeric field defines the minimum outdoor air dry-bulb temperature where the heating coil compressor turns off. The temperature for this input field must be greater than or equal to –20°C. If this input field is left blank, the default value is -8°C.

Field: Crankcase Heater Capacity

This numeric field defines the crankcase heater capacity in Watts. When the outdoor air dry-bulb temperature is below the value specified in the input field “Maximum Outdoor Dry-bulb Temperature for Crankcase Heater Operation” (described below), the crankcase heater is enabled during the time that the compressor is not running. The value for this input field must be greater than or equal to 0. If this input field is left blank, the default value is 0. To simulate a unit without a crankcase heater, enter a value of 0.

Field: Maximum Outdoor Dry-bulb Temperature for Crankcase Heater Operation

This numeric field defines the outdoor air dry-bulb temperature above which the compressor’s crankcase heater is disabled. The value for this input field must be greater than or equal to 0.0°C. If this input field is left blank, the default value is 10°C.

Field: Defrost Energy Input Ratio Modifier Curve (function of temperature)

This alpha field defines the name of a bi-quadratic performance curve (ref: Performance Curves) that parameterizes the variation of the energy input ratio (EIR) during reverse-cycle defrost periods as a function of the outdoor air dry-bulb temperature and the wet-bulb temperature of the air entering the indoor coil. The EIR is the inverse of the COP. The output of this curve is multiplied by the coil capacity, the fractional defrost time period and the runtime fraction of the heating coil to give the defrost power at the specific temperatures at which the indoor and outdoor coils are operating. This curve is only required when a reverse-cycle defrost strategy is selected. The curve is normalized to a value of 1.0 at the rating point conditions.

Field: Maximum Outdoor Dry-bulb Temperature for Defrost Operation

This numeric field defines the outdoor air dry-bulb temperature above which outdoor coil defrosting is disabled. The temperature for this input field must be greater than or equal to 0°C and less than or equal to 7.22°C. If this input field is left blank, the default value is 5°C.

Field: Defrost Strategy

This alpha field has two choices: reverse-cycle or resistive. If the reverse-cycle strategy is selected, the heating cycle is reversed periodically to provide heat to melt frost accumulated on the outdoor coil. If a resistive defrost strategy is selected, the frost is melted using an electric resistance heater. If this input field is left blank, the default defrost strategy is reverse-cycle.

Field: Defrost Control

This alpha field has two choices: timed or on-demand. If timed control is selected, the defrost time period is calculated based on a fixed value or compressor runtime whether or not frost has actually accumulated. For timed defrost control, the fractional amount of time the unit is in defrost is entered in the input field "Defrost Time Period Fraction" described below. If on-demand defrost control is selected, the defrost time period is calculated based on outdoor weather (humidity ratio) conditions. Regardless of which defrost control is selected, defrost does not occur above the user specified outdoor temperature entered in the input field "Maximum Outdoor Dry-bulb Temperature for Defrost Operation" described above. If this input field is left blank, the default defrost control is timed.

Field: Defrost Time Period Fraction

This numeric field defines the fraction of compressor runtime when the defrost cycle is active, and only applies to "timed" defrost (see Defrost Control input field above). For example, if the defrost cycle is active for 3.5 minutes for every 60 minutes of compressor runtime, then the user should enter 3.5/60 = 0.058333. The value for this input field must be greater than or equal to 0. If this input field is left blank, the default value is 0.058333.

Field: Resistive Defrost Heater Capacity

This numeric field defines the capacity of the resistive defrost heating element in Watts. This input field is used only when the selected defrost strategy is 'resistive' (see input field "Defrost Strategy" above). The value for this input field must be greater than or equal to 0. If this input field is left blank, the default value is 0.

Field: Apply Part Load Fraction to Speeds greater than 1

This field determines whether part-load impacts on coil energy use are applied when the coil is operating at speeds greater than speed 1. The allowed choices are Yes or No, with the default being No if this field is left blank. Other input fields in this object allow the user to specify a part-load fraction correlation for each speed to account for compressor start up losses (cycle on/off). For the case of a single multi-speed compressor, the part load losses may only be significant when the compressor cycles between speed 1 and off, but the losses may be extremely small when the compressor operates between speed 1 and speed 2 (or between speeds 2 and 3, etc.). In this case, the user may chose to specify NO for this input field to neglect part-load impacts on energy use at higher operating speeds. If part-load impacts on coil energy use are thought to be significant (e.g., interwined cooling coil with multiple compressors feeding individual refrigerant circuits), then the user may chose to specify YES and the part-load fraction correlations specified for speeds 2 through 4 will be applied as appropriate. The selection for this input field does not affect part-load impacts when the compressor cycles between speed 1 and off (i.e., the part-load fraction correlation for speed 1 is always applied).

Field: Fuel Type

This alpha field determines the type of fuel that the chiller uses. This field has seven choices: Electricity, NaturalGas, PropaneGas, Diesel, Gasoline, FuelOil#1, and FuelOil#2. The default is NaturalGas.

Field: Number of speeds

This field specifies the number of sets of data being entered for rated specifications, performance curves, and waste heat specifications for each cooling speed. The rated specifications consist of rated capacity, rated COP, and rated air flow rate. The performance curves consist of a total capacity modifier curve as a function of temperature, total capacity modifier curve as a function of flow fraction, energy input ratio modifier curve as a function of temperature, energy input ratio modifier curve as a function of flow fraction, and part load fraction correlation as a function of part load ratio. The waste heat specifications include the fraction of energy input to the heating coil at the fully loaded and rated conditions, and a temperature modifier. The minimum number of speeds for heating is 2 and the maximum number is 4. The number of speeds should be the same as the number of speeds for heating defined in its parent object (UnitarySystem:MultiSpeedHeatPump: AirToAir). The first set of performance inputs is for Speed 1 and should be for low speed, and the last set of performance inputs should be for high speed. For example, if only three heating speeds are defined, the first set should be for low speed (Speed 1), the second set should be for medium speed (Speed 2), and the third set should be for high speed (Speed 3). In this example, any performance inputs for Speed 4 would be neglected (since this input field specifies that the coil only has three heating speeds).

Field Group: rated specification, performance curves, and waste heat data

The performance for each heating speed must be specified as shown below. All inputs for Speed 1 are required first, followed by the inputs for Speed 2, Speed 3 and Speed 4.

Field: Rated Total Heating Capacity, Speed 1

This numeric field defines the total, full load heating capacity in watts of the DX coil unit at rated conditions for Speed 1 operation (outside air dry-bulb temperature of 8.33°C, outside air wet-bulb temperature of 6.11°C, heating coil entering air dry-bulb temperature of 21.11°C, heating coil entering air wet-bulb temperature of 15.55°C, and a heating coil air flow rate defined by field “Rated Air Volume Flow Rate, Speed 1” below). The value entered here must be greater than 0. Capacity should not include supply air fan heat.

Field: Rated COP, Speed 1

This numeric field defines the coefficient of performance (heating power output in watts divided by electrical power input in watts) of the DX heating coil unit at rated conditions for Speed 1 operation (outside air dry-bulb temperature of 8.33°C, outside air wet-bulb temperature of 6.11°C, coil entering air dry-bulb temperature of 21.11°C, coil entering air wet-bulb temperature of 15.55°C, and a heating coil air flow rate defined by field “Rated Air Volume Flow Rate, Speed 1” below). The value entered here must be greater than 0. The input power includes power for the compressor(s) and outdoor fan(s) but does not include the power consumption of the indoor supply air fan. The heating power output is the value entered above in the field “Rated Total Heating Capacity”.

Field: Rated Air Volume Flow Rate, Speed 1

This numeric field defines the volume air flow rate, in m^3 per second, across the DX heating coil at rated conditions for Speed 1 operation. The value entered here must be greater than 0. The rated air volume flow rate should be between 0.00004027 m^3/s and 0.00006041 m^3/s per watt of rated total heating capacity. The rated total heating capacity and rated COP should be performance information for the unit with outside air dry-bulb temperature of 8.33°C, outside air wet-bulb temperature of 6.11°C, heating coil entering air dry-bulb temperature of 21.11°C, heating coil entering air wet-bulb temperature of 15.55°C, and the rated air volume flow rate defined here.

Field: Total Heating Capacity Modifier Curve, Speed 1 (function of temperature)

This alpha field defines the name of a bi-quadratic, quadratic or cubic performance curve for Speed 1 (ref: Performance Curves) that parameterizes the variation of the total heating capacity as a function of the both the indoor and outdoor air dry-bulb temperature or just the outdoor air dry-bulb temperature depending on the type of curve selected. The bi-quadratic curve is recommended if sufficient manufacturer data is available as it provides sensitivity to the indoor air dry-bulb temperature and a more realistic output. The output of this curve is multiplied by the rated total heating capacity to give the total heating capacity at specific temperature operating conditions (i.e., at an indoor air dry-bulb temperature or outdoor air dry-bulb temperature different from the rating point temperature). The curve is normalized to have the value of 1.0 at the rating point.

Field: Total Heating Capacity Modifier Curve, Speed 1 (function of flow fraction)

This alpha field defines the name of a quadratic or cubic performance curve for Speed 1 (ref: Performance Curves) that parameterizes the variation of total heating capacity as a function of the ratio of actual air flow rate across the heating coil to the rated air flow rate (i.e., fraction of full load flow). The output of this curve is multiplied by the rated total heating capacity and the total heating capacity modifier curve (function of temperature) to give the total heating capacity at the specific temperature and air flow conditions at which the coil is operating. The curve is normalized to have the value of 1.0 when the actual air flow rate equals the rated air flow rate.

Field: Energy Input Ratio Modifier Curve, Speed 1 (function of temperature)

This alpha field defines the name of a bi-quadratic, quadratic or cubic performance curve for Speed 1 (ref: Performance Curves) that parameterizes the variation of the energy input ratio (EIR) as a function of the both the indoor and outdoor air dry-bulb temperature or just the outdoor air dry-bulb temperature depending on the type of curve selected. The bi-quadratic curve is recommended if sufficient manufacturer data is available as it provides sensitivity to the indoor air dry-bulb temperature and a more realistic output. The EIR is the inverse of the COP. The output of this curve is multiplied by the rated EIR (inverse of rated COP) to give the EIR at specific temperature operating conditions (i.e., at an indoor air dry-bulb temperature or outdoor air dry-bulb temperature different from the rating point temperature). The curve is normalized to have the value of 1.0 at the rating point.

Field: Energy Input Ratio Modifier Curve, Speed 1 (function of flow fraction)

This alpha field defines the name of a quadratic or cubic performance curve for Speed 1 (ref: Performance Curves) that parameterizes the variation of the energy input ratio (EIR) as a function of the ratio of actual air flow rate across the heating coil to the rated air flow rate (i.e., fraction of full load flow). The EIR is the inverse of the COP. The output of this curve is multiplied by the rated EIR and the EIR modifier curve (function of temperature) to give the EIR at the specific temperature and air flow conditions at which the coil is operating. This curve is normalized to a value of 1.0 when the actual air flow rate equals the rated air flow rate.

Field: Part Load Fraction Correlation, Speed 1 (function of part load ratio)

This alpha field defines the name of a quadratic or cubic performance curve for Speed 1 (Ref: Performance Curves) that parameterizes the variation of electrical power input to the DX unit as a function of the part load ratio (PLR, sensible cooling load/steady-state sensible cooling capacity). The product of the rated EIR and EIR modifier curves is divided by the output of this curve to give the "effective" EIR for a given simulation time step. The part load fraction (PLF) correlation accounts for efficiency losses due to compressor cycling.

The part load fraction correlation should be normalized to a value of 1.0 when the part load ratio equals 1.0 (i.e., no efficiency losses when the compressor(s) run continuously for the simulation time step). For PLR values between 0 and 1 ($0 <= PLR < 1$), the following rules apply:

$PLF >= 0.7$ and $PLF >= PLR$

If PLF < 0.7 a warning message is issued, the program resets the PLF value to 0.7, and the simulation proceeds. The runtime fraction of the coil is defined as PLR/PLF. If PLF < PLR, then a warning message is issued and the runtime fraction of the coil is limited to 1.0.

A typical part load fraction correlation for a conventional DX heating coil (Speed 1) would be:

PLF = 0.85 + 0.15(PLR)

If the user wishes to model no efficiency degradation due to compressor cycling, the part load fraction correlation should be defined as follows:

PLF = 1.0 + 0.0(PLR)

Field: Rated Waste heat fraction of heat input, Speed 1

The fraction of heat input to heating that is available as recoverable waste heat at full load and rated conditions for Speed 1 operation.

Field: Waste heat Modifier Curve, Speed 1 (function of temperature)

The name of a bi-quadratic performance curve (ref: Performance Curves) that parameterizes the variation of the waste heat recovery as a function of outdoor dry-bulb temperature and the entering coil dry-bulb temperature for Speed 1. The output of this curve is multiplied by the rated recoverable waste heat at specific temperature operating conditions (i.e., at temperatures different from the rating point). The curve is normalized to a value of 1.0 at the rating point. When the fuel type is electricity, the field is either left blank or ignored by the program.

- reduced for brevity –

Field: Rated Total Heating Capacity, Speed n

This numeric field defines the total, full load heating capacity in watts of the DX coil unit at rated conditions for Speed n operation (outside air dry-bulb temperature of 8.33°C, outside air wet-bulb temperature of 6.11°C, heating coil entering air dry-bulb temperature of 21.11°C, heating coil entering air wet-bulb temperature of 15.55°C, and a heating coil air flow rate defined by field “Rated Air Volume Flow Rate, Speed n” below). The value entered here must be greater than 0. Capacity should not include supply air fan heat.

Field: Rated COP, Speed n

This numeric field defines the coefficient of performance (heating power output in watts divided by electrical power input in watts) of the DX heating coil unit at rated conditions for Speed n operation (outside air dry-bulb temperature of 8.33°C, outside air wet-bulb temperature of 6.11°C, coil entering air dry-bulb temperature of 21.11°C, coil entering air wet-bulb temperature of 15.55°C, and a heating coil air flow rate defined by field “Rated Air Volume Flow Rate, Speed n” below). The value entered here must be greater than 0. The input power includes power for the compressor(s) and outdoor fan(s) but does not include the power consumption of the indoor supply air fan. The heating power output is the value entered above in the field “Rated Total Heating Capacity”.

Field: Rated Air Volume Flow Rate, Speed n

This numeric field defines the volume air flow rate, in m^3 per second, across the DX heating coil at rated conditions for Speed n. The value entered here must be greater than 0. The rated air volume flow rate should be between 0.00004027 m^3/s and 0.00006041 m^3/s per watt of rated total heating capacity. The rated total heating capacity and rated COP should be performance information for the unit with outside air dry-bulb temperature of 8.33°C, outside air wet-bulb temperature of 6.11°C, heating coil entering air dry-bulb temperature of 21.11°C, heating coil entering air wet-bulb temperature of 15.55°C, and the rated air volume flow rate defined here.

Field: Total Heating Capacity Modifier Curve, Speed n (function of temperature)

This alpha field defines the name of a bi-quadratic, quadratic or cubic performance curve for Speed n (ref: Performance Curves) that parameterizes the variation of the total heating capacity as a function of the both the indoor and outdoor air dry-bulb temperature or just the outdoor air dry-bulb temperature depending on the type of curve selected. The bi-quadratic curve is recommended if sufficient manufacturer data is available as it provides sensitivity to the indoor air dry-bulb temperature and a more realistic output. The output of this curve is multiplied by the rated total heating capacity to give the total heating capacity at specific temperature operating conditions (i.e., at an indoor air dry-bulb temperature or outdoor air dry-bulb temperature different from the rating point temperature). The curve is normalized to have the value of 1.0 at the rating point.

Field: Total Heating Capacity Modifier Curve, Speed n (function of flow fraction)

This alpha field defines the name of a quadratic or cubic performance curve for Speed n (ref: Performance Curves) that parameterizes the variation of total heating capacity as a function of the ratio of actual air flow rate across the heating coil to the rated air flow rate (i.e., fraction of full load flow). The output of this curve is multiplied by the rated total heating capacity and the total heating capacity modifier curve (function of temperature) to give the total heating capacity at the specific temperature and air flow conditions at which the coil is operating. The curve is normalized to have the value of 1.0 when the actual air flow rate equals the rated air flow rate.

Field: Energy Input Ratio Modifier Curve, Speed n (function of temperature)

This alpha field defines the name of a bi-quadratic, quadratic or cubic performance curve for Speed n (ref: Performance Curves) that parameterizes the variation of the energy input ratio (EIR) as a function of the both the indoor and outdoor air dry-bulb temperature or just the outdoor air dry-bulb temperature depending on the type of curve selected. The bi-quadratic curve is recommended if sufficient manufacturer data is available as it provides sensitivity to the indoor air dry-bulb temperature and a more realistic output. The EIR is the inverse of the COP. The output of this curve is multiplied by the rated EIR (inverse of rated COP) to give the EIR at specific temperature operating conditions (i.e., at an indoor air dry-bulb temperature or outdoor air dry-bulb temperature different from the rating point temperature). The curve is normalized to have the value of 1.0 at the rating point.

Field: Energy Input Ratio Modifier Curve, Speed n (function of flow fraction)

This alpha field defines the name of a quadratic or cubic performance curve for Speed n (ref: Performance Curves) that parameterizes the variation of the energy input ratio (EIR) as a function of the ratio of actual air flow rate across the heating coil to the rated air flow rate (i.e., fraction of full load flow). The EIR is the inverse of the COP. The output of this curve is multiplied by the rated EIR and the EIR modifier curve (function of temperature) to give the EIR at the specific temperature and air flow conditions at which the coil is operating. This curve is normalized to a value of 1.0 when the actual air flow rate equals the rated air flow rate.

Field: Part Load Fraction Correlation, Speed n (function of part load ratio)

This alpha field defines the name of a quadratic or cubic performance curve for Speed n (Ref: Performance Curves) that parameterizes the variation of electrical power input to the DX unit as a function of the part load ratio (PLR, sensible cooling load/steady-state sensible cooling capacity). The product of the rated EIR and EIR modifier curves is divided by the output of this curve to give the “effective” EIR for a given simulation time step. The part load fraction (PLF) correlation accounts for efficiency losses due to compressor cycling.

The part load fraction correlation should be normalized to a value of 1.0 when the part load ratio equals 1.0 (i.e., no efficiency losses when the compressor(s) run continuously for the simulation time step). For PLR values between 0 and 1 (0 <= PLR < 1), the following rules apply:

PLF >= 0.7   and   PLF >= PLR

If PLF < 0.7 a warning message is issued, the program resets the PLF value to 0.7, and the simulation proceeds. The runtime fraction of the coil is defined as PLR/PLF. If PLF < PLR, then a warning message is issued and the runtime fraction of the coil is limited to 1.0.

A typical part load fraction correlation for a conventional DX heating coil (Speed n) would be:

PLF = 0.85 + 0.15(PLR)

If the user wishes to model no efficiency degradation due to compressor cycling, the part load fraction correlation should be defined as follows:

PLF = 1.0 + 0.0(PLR)

Field: Rated Waste heat fraction of heat input, Speed n

The fraction of heat input to heating that is available as recoverable waste heat at full load and rated conditions for Speed n.

Field: Waste heat Modifier Curve, Speed n (function of temperature)

The name of a bi-quadratic performance curve (ref: Performance Curves) that parameterizes the variation of the waste heat recovery as a function of outdoor dry-bulb temperature and the entering coil dry-bulb temperature for Speed n. The output of this curve is multiplied by the rated recoverable waste heat at specific temperature operating conditions (i.e., at temperatures different from the rating point). The curve is normalized to a value of 1.0 at the rating point. When the fuel type is electricity, the field is either left blank or ignored by the program.

Below is the input data dictionary description of the DX heating coil.

```
COIL:DX:MULTISPEED:HEATING,
       \min-fields 37
  A1 , \field Coil name
       \required-field
       \reference HeatingCoilsDX
       \type alpha
  A2 , \field Availability Schedule
       \required-field
       \type object-list
       \object-list ScheduleNames
  A3 , \field Coil Air Inlet Node
       \required-field
       \type alpha
  A4 , \field Coil Air Outlet Node
       \required-field
       \type alpha
  A5, \field Supply Air Fan Operation Mode
       \required-field
       \type choice
       \key CycFanCycComp
       \key ContFanCycComp
  N1 , \field Minimum Outdoor Dry-bulb Temperature for Compressor Operation
       \type real
       \minimum -20.0
       \default -8.0
       \units C
  N2 , \field Crankcase Heater Capacity
       \type real
       \minimum 0.0
       \default 0.0
       \units W
       \ip-units W
  N3 , \field Maximum Outdoor Dry-bulb Temperature for Crankcase Heater Operation
       \type real
       \minimum 0.0
       \default 10.0
       \units C
  A6 , \field Defrost energy input ratio modifier curve (function of temperature)
       \type object-list
       \object-list BiquadraticCurves
       \note bi-quadratic curve = a + b*wb + c*wb**2 + d*oat + e*oat**2 + f*wb*oat
       \note wb = wet-bulb temperature (C) of air entering the indoor coil
       \note oat = outdoor air dry-bulb temperature (C)
       \note only required if reverse-cycle defrost strategy is specified
  N4 , \field Maximum Outdoor Dry-bulb Temperature for Defrost Operation
       \type real
       \minimum 0.0
       \maximum 7.22
       \default 5.0
       \units C
  A7 , \field Defrost Strategy
       \type choice
       \key reverse-cycle
       \key resistive
       \default reverse-cycle
  A8 , \field Defrost Control
       \type choice
       \key timed
       \key on-demand
       \default timed
  N5 , \field Defrost Time Period Fraction
       \type real
       \minimum 0.0
       \default 0.058333
       \note fraction of time in defrost mode
       \note only applicable if timed defrost control is specified
```

```
  N6 , \field Resistive Defrost Heater Capacity
       \type real
       \minimum 0.0
       \default 0.0
       \autosizable
       \units W
       \note only applicable if resistive defrost strategy is specified
       \ip-units W
  A9 , \field Apply Part Load Fraction to Speeds greater than 1
       \type choice
       \key Yes
       \key No
       \default No
  A10, \field Fuel Type
       \type choice
       \key Electricity
       \key NaturalGas
       \key PropaneGas
       \key Diesel
       \key Gasoline
       \key FuelOil#1
       \key FuelOil#2
       \default NaturalGas
  N7 , \field Number of speeds
       \required-field
       \type integer
       \minimum 2
       \maximum 4
       \note Enter the number of the following sets of data for coil capacity, COP,
       \note flow rate, and associated curves.
  N8 , \field Rated Total Heating Capacity, Speed 1
       \required-field
       \type real
       \units W
       \minimum> 0.0
       \autosizable
       \note capacity excluding supply air fan heat
       \note rating point outside dry-bulb temp 8.33 C, outside wet-bulb temp 6.11 C
       \note rating point heating coil entering air dry-bulb 21.11 C, coil entering
       \note wetbulb 15.55 C
  N9 , \field Rated COP, Speed 1
       \required-field
       \type real
       \minimum> 0.0
       \note does not include supply air fan heat or supply air fan electrical energy
  N10, \field Rated Air Volume Flow Rate, Speed 1
       \required-field
       \type real
       \units m3/s
       \minimum> 0.0
       \autosizable
       \note volume flow rate corresponding to rated total capacity
       \note should be between 0.00004027 m3/s and .00006041 m3/s per watt of rated total
       \note heating capacity
  A11, \field Total heating capacity modifier curve, Speed 1 (function of temperature)
       \required-field
       \type object-list
       \object-list Biquatric_Quadratic_CubicCurves
       \note quadratic curve = a + b*oat + c*oat**2
       \note cubic curve = a + b*oat + c*oat**2 + d*oat**3
       \note bi-quadratic curve = a + b*iat + c*iat**2 + d*oat + e*oat**2 + f*iat*oat
       \note oat = outdoor air dry-bulb temperature (C)
       \note iat = indoor air dry-bulb temperature (C)
       \note Bi-quadratic curve is recommended if sufficient manufacturer data is
       \note available for the heating capacity to be sensitive to both iat and oat.
```

```
A12, \field Total heating capacity modifier curve, Speed 1 (function of flow fraction)
     \required-field
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*ff + c*ff**2
     \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
     \note ff = fraction of the full load flow
A13, \field Energy input ratio modifier curve, Speed 1 (function of temperature)
     \required-field
     \type object-list
     \object-list Biquatric_Quadratic_CubicCurves
     \note quadratic curve = a + b*oat + c*oat**2
     \note cubic curve = a + b*oat + c*oat**2 + d*oat**3
     \note bi-quadratic curve = a + b*iat + c*iat**2 + d*oat + e*oat**2 + f*iat*oat
     \note oat = outdoor air dry-bulb temperature (C)
     \note iat = indoor air dry-bulb temperature (C)
     \note Bi-quadratic curve is recommended if sufficient manufacturer data is
     \note available for the energy input ratio to be sensitive to both iat and oat.
A14, \field Energy input ratio modifier curve, Speed 1 (function of flow fraction)
     \required-field
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*ff + c*ff**2
     \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
     \note ff = fraction of the full load flow
A15, \field Part load fraction correlation, Speed 1 (function of part load ratio)
     \required-field
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*PLR + c*PLR**2
     \note cubic curve = a + b*PLR + c*PLR**2 + d*PLR**3
     \note PLR = part load ratio (sensible heating load/steady-state heating capacity)
N11, \field Rated waste heat fraction of power input, Speed 1
     \required-field
     \type real
     \units dimensionless
     \minimum> 0.0
     \maximum 1.0
     \note recoverable waste heat at full load and rated conditions
A16, \field Waste heat modifier curve, Speed 1 (function of temperature)
     \required-field
     \type alpha
     \object-list BiQuadraticCurves
     \note curve = a + b*odb + c*odb**2 + d*db + e*db**2 + f*odb*db
     \note odb = Outdoor air drybulb temperature (C)
     \note db = entering coil drybulb temperature (C)
N12, \field Rated Total Heating Capacity, Speed 2
     \required-field
     \type real
     \units W
     \minimum> 0.0
     \autosizable
     \note capacity excluding supply air fan heat
     \note rating point outside dry-bulb temp 8.33 C, outside wet-bulb temp 6.11 C
     \note rating point heating coil entering air dry-bulb 21.11 C, coil entering
     \note wetbulb 15.55 C
N13, \field Rated COP, Speed 2
     \required-field
     \type real
     \minimum> 0.0
     \note does not include supply air fan heat or supply air fan electrical energy
```

```
N14, \field Rated Air Volume Flow Rate, Speed 2
     \required-field
     \type real
     \units m3/s
     \minimum> 0.0
     \autosizable
     \note volume flow rate corresponding to rated total capacity
     \note should be between 0.00004027 m3/s and .00006041 m3/s per watt of rated total
     \note heating capacity
A17, \field Total heating capacity modifier curve, Speed 2 (function of temperature)
     \required-field
     \type object-list
     \object-list Biquatric_Quadratic_CubicCurves
     \note quadratic curve = a + b*oat + c*oat**2
     \note cubic curve = a + b*oat + c*oat**2 + d*oat**3
     \note bi-quadratic curve = a + b*iat + c*iat**2 + d*oat + e*oat**2 + f*iat*oat
     \note oat = outdoor air dry-bulb temperature (C)
     \note iat = indoor air dry-bulb temperature (C)
     \note Bi-quadratic curve is recommended if sufficient manufacturer data is
     \note available for the heating capacity to be sensitive to both iat and oat.
A18, \field Total heating capacity modifier curve, Speed 2 (function of flow fraction)
     \required-field
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*ff + c*ff**2
     \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
     \note ff = fraction of the full load flow
A19, \field Energy input ratio modifier curve, Speed 2 (function of temperature)
     \required-field
     \type object-list
     \object-list Biquatric_Quadratic_CubicCurves
     \note quadratic curve = a + b*oat + c*oat**2
     \note cubic curve = a + b*oat + c*oat**2 + d*oat**3
     \note bi-quadratic curve = a + b*iat + c*iat**2 + d*oat + e*oat**2 + f*iat*oat
     \note oat = outdoor air dry-bulb temperature (C)
     \note iat = indoor air dry-bulb temperature (C)
     \note Bi-quadratic curve is recommended if sufficient manufacturer data is
     \note available for the energy input ratio to be sensitive to both iat and oat.
A20, \field Energy input ratio modifier curve, Speed 2 (function of flow fraction)
     \required-field
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*ff + c*ff**2
     \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
     \note ff = fraction of the full load flow
A21, \field Part load fraction correlation, Speed 2 (function of part load ratio)
     \required-field
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*PLR + c*PLR**2
     \note cubic curve = a + b*PLR + c*PLR**2 + d*PLR**3
     \note PLR = part load ratio (sensible heating load/steady-state heating capacity)
N15, \field Rated waste heat fraction of power input, Speed 2
     \required-field
     \type real
     \units dimensionless
     \minimum> 0.0
     \maximum 1.0
     \note recoverable waste heat at full load and rated conditions
A22, \field Waste heat modifier curve, Speed 2 (function of temperature)
     \required-field
     \type alpha
     \object-list BiQuadraticCurves
     \note curve = a + b*odb + c*odb**2 + d*db + e*db**2 + f*odb*db
     \note odb = Outdoor air drybulb temperature (C)
     \note db = entering coil drybulb temperature (C)
```

```
N16, \field Rated Total Heating Capacity, Speed 3
     \type real
     \units W
     \minimum> 0.0
     \autosizable
     \note capacity excluding supply air fan heat
     \note rating point outside dry-bulb temp 8.33 C, outside wet-bulb temp 6.11 C
     \note rating point heating coil entering air dry-bulb 21.11 C, coil entering
     \note wetbulb 15.55 C
N17, \field Rated COP, Speed 3
     \type real
     \minimum> 0.0
     \note does not include supply air fan heat or supply air fan electrical energy
N18, \field Rated Air Volume Flow Rate, Speed 3
     \type real
     \units m3/s
     \minimum> 0.0
     \autosizable
     \note volume flow rate corresponding to rated total capacity
     \note should be between 0.00004027 m3/s and .00006041 m3/s per watt of rated total
     \note heating capacity
A23, \field Total heating capacity modifier curve, Speed 3 (function of temperature)
     \type object-list
     \object-list Biquatric_Quadratic_CubicCurves
     \note quadratic curve = a + b*oat + c*oat**2
     \note cubic curve = a + b*oat + c*oat**2 + d*oat**3
     \note bi-quadratic curve = a + b*iat + c*iat**2 + d*oat + e*oat**2 + f*iat*oat
     \note oat = outdoor air dry-bulb temperature (C)
     \note iat = indoor air dry-bulb temperature (C)
     \note Bi-quadratic curve is recommended if sufficient manufacturer data is
     \note available for the heating capacity to be sensitive to both iat and oat.
A24, \field Total heating capacity modifier curve, Speed 3 (function of flow fraction)
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*ff + c*ff**2
     \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
     \note ff = fraction of the full load flow
A25, \field Energy input ratio modifier curve, Speed 3 (function of temperature)
     \type object-list
     \object-list Biquatric_Quadratic_CubicCurves
     \note quadratic curve = a + b*oat + c*oat**2
     \note cubic curve = a + b*oat + c*oat**2 + d*oat**3
     \note bi-quadratic curve = a + b*iat + c*iat**2 + d*oat + e*oat**2 + f*iat*oat
     \note oat = outdoor air dry-bulb temperature (C)
     \note iat = indoor air dry-bulb temperature (C)
     \note Bi-quadratic curve is recommended if sufficient manufacturer data is
     \note available for the energy input ratio to be sensitive to both iat and oat.
A26, \field Energy input ratio modifier curve, Speed 3 (function of flow fraction)
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*ff + c*ff**2
     \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
     \note ff = fraction of the full load flow
A27, \field Part load fraction correlation, Speed 3 (function of part load ratio)
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*PLR + c*PLR**2
     \note cubic curve = a + b*PLR + c*PLR**2 + d*PLR**3
     \note PLR = part load ratio (sensible heating load/steady-state heating capacity)
N19, \field Rated waste heat fraction of power input, Speed 3
     \type real
     \units dimensionless
     \minimum> 0.0
     \maximum 1.0
     \note recoverable waste heat at full load and rated conditions
```

```
A28, \field Waste heat modifier curve, Speed 3 (function of temperature)
     \type alpha
     \object-list BiQuadraticCurves
     \note curve = a + b*odb + c*odb**2 + d*db + e*db**2 + f*odb*db
     \note odb = Outdoor air drybulb temperature (C)
     \note db = entering coil drybulb temperature (C)
N20, \field Rated Total Heating Capacity, Speed 4
     \type real
     \units W
     \minimum> 0.0
     \autosizable
     \note capacity excluding supply air fan heat
     \note rating point outside dry-bulb temp 8.33 C, outside wet-bulb temp 6.11 C
     \note rating point heating coil entering air dry-bulb 21.11 C, coil entering
     \note wetbulb 15.55 C
N21, \field Rated COP, Speed 4
     \type real
     \minimum> 0.0
     \note does not include supply air fan heat or supply air fan electrical energy
N22, \field Rated Air Volume Flow Rate, Speed 4
     \type real
     \units m3/s
     \minimum> 0.0
     \autosizable
     \note volume flow rate corresponding to rated total capacity
     \note should be between 0.00004027 m3/s and .00006041 m3/s per watt of rated total
     \note heating capacity
A29, \field Total heating capacity modifier curve, Speed 4 (function of temperature)
     \type object-list
     \object-list Biquatric_Quadratic_CubicCurves
     \note quadratic curve = a + b*oat + c*oat**2
     \note cubic curve = a + b*oat + c*oat**2 + d*oat**3
     \note bi-quadratic curve = a + b*iat + c*iat**2 + d*oat + e*oat**2 + f*iat*oat
     \note oat = outdoor air dry-bulb temperature (C)
     \note iat = indoor air dry-bulb temperature (C)
     \note Bi-quadratic curve is recommended if sufficient manufacturer data is
     \note available for the heating capacity to be sensitive to both iat and oat.
A30, \field Total heating capacity modifier curve, Speed 4 (function of flow fraction)
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*ff + c*ff**2
     \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
     \note ff = fraction of the full load flow
A31, \field Energy input ratio modifier curve, Speed 4 (function of temperature)
     \type object-list
     \object-list Biquatric_Quadratic_CubicCurves
     \note quadratic curve = a + b*oat + c*oat**2
     \note cubic curve = a + b*oat + c*oat**2 + d*oat**3
     \note bi-quadratic curve = a + b*iat + c*iat**2 + d*oat + e*oat**2 + f*iat*oat
     \note oat = outdoor air dry-bulb temperature (C)
     \note iat = indoor air dry-bulb temperature (C)
     \note Bi-quadratic curve is recommended if sufficient manufacturer data is
     \note available for the energy input ratio to be sensitive to both iat and oat.
A32, \field Energy input ratio modifier curve, Speed 4 (function of flow fraction)
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*ff + c*ff**2
     \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
     \note ff = fraction of the full load flow
A33, \field Part load fraction correlation, Speed 4 (function of part load ratio)
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*PLR + c*PLR**2
     \note cubic curve = a + b*PLR + c*PLR**2 + d*PLR**3
     \note PLR = part load ratio (sensible heating load/steady-state heating capacity)
```

```
N23, \field Rated waste heat fraction of power input, Speed 4
     \type real
     \units dimensionless
     \minimum> 0.0
     \maximum 1.0
     \note recoverable waste heat at full load and rated conditions
A34; \field Waste heat modifier curve, Speed 4 (function of temperature)
     \type alpha
     \object-list BiQuadraticCurves
     \note curve = a + b*odb + c*odb**2 + d*db + e*db**2 + f*odb*db
     \note odb = Outdoor air drybulb temperature (C)
     \note db = entering coil drybulb temperature (C)
```

Following is an example input for this multispeed DX heating coil.

```
COIL:DX:MultiSpeed:Heating,
  Heat Pump DX Heating Coil 1,  !- Name of heat pump heating coil
  FanAndCoilAvailSched,     !- Availability Schedule
  Heating Coil Air Inlet Node,  !- Coil Air Inlet Node
  SuppHeating Coil Air Inlet Node,  !- Coil Air Outlet Node
  CycFanCycComp,            !- Supply Air Fan Operation Mode
  -8.0,                     !- Minimum Outdoor Dry-bulb Temperature for Compressor Operation {C}
  200.0,                    !- Crankcase Heater Capacity {W}
  10.0,                     !- Maximum Outdoor Dry-bulb Temperature for Crankcase Heater
                            !- Operation {C}
  HPACDefrostCAPFT,         !- Defrost energy input ratio modifier curve (temperature)
  7.22,                     !- Maximum Outdoor Dry-bulb Temperature for Defrost Operation
  reverse-cycle,            !- Defrost Strategy
  timed,                    !- Defrost Control
  0.058333,                 !- Defrost Time Period Fraction
  2000.0,                   !- Resistive Defrost Heater Capacity {W}
  No,                       !- Apply Part Load Fraction to Speeds greater than 1
  NaturalGas,               !- Fuel type
  4,                        !- Number of speeds
  7500,                     !- Rated Total Heating Capacity, Speed 1 {W}
  2.75,                     !- Rated COP, Speed 1
  0.45,                     !- Rated Air Volume Flow Rate, Speed 1 {m3/s}
  HPACHeatCapFT Speed 1,    !- Total Heating Capacity Modifier Curve, Speed 1 (temperature)
  HPACHeatCapFF Speed 1,    !- Total Heating capacity modifier curve, Speed 1 (flow fraction)
  HPACHeatEIRFT Speed 1,    !- Energy input ratio modifier curve, Speed 1 (temperature)
  HPACHeatEIRFF Speed 1,    !- Energy input ratio modifier curve, Speed 1 (flow fraction)
  HPACHeatPLFFPLR Speed 1,  !- Part load fraction correlation, Speed 1 (part load ratio)
  0.2,                      !- Rated waste heat fraction of power input, Speed 1
  HAPCHeatWHFT Speed 1,     !- Waste heat modifier curve, Speed 1 (temperature)
  17500,                    !- Rated Total Heating Capacity, Speed 2 {W}
  2.75,                     !- Rated COP, Speed 2
  0.85,                     !- Rated Air Volume Flow Rate, Speed 2 {m3/s}
  HPACHeatCapFT Speed 2,    !- Total Heating Capacity Modifier Curve, Speed 2 (temperature)
  HPACHeatCapFF Speed 2,    !- Total Heating capacity modifier curve, Speed 2 (flow fraction)
  HPACHeatEIRFT Speed 2,    !- Energy input ratio modifier curve, Speed 2 (temperature)
  HPACHeatEIRFF Speed 2,    !- Energy input ratio modifier curve, Speed 2 (flow fraction)
  HPACHeatPLFFPLR Speed 2,  !- Part load fraction correlation, Speed 2 (part load ratio)
  0.2,                      !- Rated waste heat fraction of power input, Speed 2
  HAPCHeatWHFT Speed 2,     !- Waste heat modifier curve, Speed 2 (temperature)
  25500,                    !- Rated Total Heating Capacity, Speed 3 {W}
  2.75,                     !- Rated COP, Speed 3
  1.25,                     !- Rated Air Volume Flow Rate, Speed 3 {m3/s}
  HPACHeatCapFT Speed 3,    !- Total Heating Capacity Modifier Curve, Speed 3 (temperature)
  HPACHeatCapFF Speed 3,    !- Total Heating capacity modifier curve, Speed 3 (flow fraction)
  HPACHeatEIRFT Speed 3,    !- Energy input ratio modifier curve, Speed 3 (temperature)
  HPACHeatEIRFF Speed 3,    !- Energy input ratio modifier curve, Speed 3 (flow fraction)
  HPACHeatPLFFPLR Speed 3,  !- Part load fraction correlation, Speed 3 (part load ratio)
  0.2,                      !- Rated waste heat fraction of power input, Speed 3
  HAPCHeatWHFT Speed 3,     !- Waste heat modifier curve, Speed 3 (temperature)
  35500,                    !- Rated Total Heating Capacity, Speed 4 {W}
  2.75,                     !- Rated COP, Speed 4
  1.75,                     !- Rated Air Volume Flow Rate, Speed 4 {m3/s}
  HPACHeatCapFT Speed 4,    !- Total Heating Capacity Modifier Curve, Speed 4 (temperature)
  HPACHeatCapFF Speed 4,    !- Total Heating capacity modifier curve, Speed 4 (flow fraction)
  HPACHeatEIRFT Speed 4,    !- Energy input ratio modifier curve, Speed 4 (temperature)
  HPACHeatEIRFF Speed 4,    !- Energy input ratio modifier curve, Speed 4 (flow fraction)
  HPACHeatPLFFPLR Speed 4,  !- Part load fraction correlation, Speed 4 (part load ratio)
  0.2,                      !- Rated waste heat fraction of power input, Speed 4
  HAPCHeatWHFT Speed 4;     !- Waste heat modifier curve, Speed 4 (temperature)
```

DX Heating Coil Outputs

```
HVAC,Average,DX Coil Total Heating Rate[W]
HVAC,Sum,DX Coil Total Heating Energy[J]
HVAC,Average,DX Heating Coil <FuelType> Power[W]
HVAC,Sum,DX Heating Coil <FuelType> Consumption[J]
HVAC,Average,DX Heating Coil Electric Defrost Power[W]
HVAC,Sum,DX Heating Coil Electric Defrost Consumption[J]
```

```
HVAC,Average,DX Heating Coil NaturalGas Defrost Power[W]
HVAC,Sum,DX Heating Coil NaturalGas Defrost Consumption[J]
HVAC,Average,DX Heating Coil Crankcase Heater Power[W]
HVAC,Sum,DX Heating Coil Crankcase Heater Consumption[J]
HVAC,Average,DX Heating Coil Runtime Fraction
```

DX Coil Total Heating Rate [W]

This field is the total heating rate output of the DX coil in Watts. This is determined by the coil inlet and outlet air conditions and the air mass flow rate through the coil.

DX Coil Total Heating Energy[J]

This is the total heating output of the DX coil in Joules over the time step being reported. This is determined by the coil inlet and outlet air conditions and the air mass flow rate through the coil. This output is also added to a report meter with Resource Type = EnergyTransfer, End Use Key = HeatingCoil, Group Key = System (ref. Report Meter).

DX Heating Coil <FuelType> Power [W]

This output variable is the input fuel type power for the heating coil in the unit of Watts, averaged during the report period.

DX Cooling Coil <FuelType> Consumption [J]

This output variable is the input fuel type consumption for the multispeed heating coil in the unit of Joules, summed during the report period. This output is also added to a report meter with Resource Type = <FuelType>, End Use Key = Heating, Group Key = System (ref. Report Meter).

> Note: The FuelType defined in the above two output variables depends on the input in the fuel type filed. In addition to Electricity, Valid fuel types are NaturalGas, Propane, FuelOil#1, FuelOil#2, Coal, Diesel, and Gasoline.

DX Heating Coil Electric Defrost Power [W]

This is the electricity consumption rate of the DX coil unit in Watts when the unit is in defrost mode (reverse-cycle or resistive). The variable is available when the defrost mode is resistive or the fuel type is electricity.

DX Heating Coil Electric Defrost Consumption [J]

This is the electricity consumption of the DX coil unit in Joules for the time step being reported. This consumption is applicable when the unit is in defrost mode (reverse-cycle or resistive). The variable is available when the defrost mode is resistive or the fuel type is electricity.

DX Heating Coil <FuelType> Defrost Power [W]

This is the fuel consumption rate of the DX coil unit in Watts when the unit is in defrost mode (reverse-cycle). The variable is available when the defrost mode is reverse-cycle and the fuel type is non-electricity.

DX Heating Coil <FuelType> Defrost Consumption[J]

This is the fuel consumption of the DX coil unit in Joules for the time step being reported. This consumption is applicable when the unit is in defrost mode (reverse-cycle). The variable is available when the defrost mode is reverse-cycle and the fuel type is non-electricity.

DX Heating Coil Crankcase Heater Power [W]

This is the average electricity consumption rate of the DX coil compressor's crankcase heater in Watts for the time step being reported. When a companion cooling coil exits, the crankcase heater power of the companion cool coil is also reported in this variable.

DX Heating Coil Crankcase Heater Consumption [J]

This is the electricity consumption of the DX coil compressor's crankcase heater in Joules for the time step being reported. This output is also added to a report meter with Resource Type = Electricity, End Use Key = Heating, Group Key = System (ref. Report Meter). When a companion cooling coil exits, the crankcase heater power of the companion cool coil is also reported in this variable.

DX Heating Coil Runtime Fraction

This is the runtime fraction of the DX heating coil compressor and outdoor fan(s) for the time step being reported. When the heating speed is above 1, this output is the run time fraction for the higher speed.

Engineering Document for Coil:DX:MultiSpeed:Heating

Overview

This model (object name Coil:DX:MultiSpeed:Heating) simulates the performance of an air-to-air direct expansion (DX) heating system. The main difference compared to the other heating coil model (Coil:DX:HeatingEmpirical) is that this heating coil allows modeling of two to four discrete compressor speeds. Each speed has a set of corresponding performance information at rated conditions along with curve fits for variations in total capacity, energy input ratio and part-load fraction to determine the performance of the unit at part-load conditions (DOE 1982). The full load supply airflow rate is dependent on the speed number and is set by its parent object (Ref: UnitarySystem:MultiSpeedHeatPump:AirToAir). The part-load impact on coil energy use is automatically applied to the lowest speed. A choice is provided to determine whether part-load impacts on coil energy use are applied when the coil is operating at speeds greater than Speed 1. Adjustment factors applied to total capacity and input power to account for frost formation on the outdoor coil are calculated at each speed.

This model simulates the thermal performance of the indoor DX heating coil, and the power consumption of the outdoor unit (multispeed compressor, fans, crankcase heaters and defrost heaters). The performance of the indoor supply air fan varies widely from system to system depending on control strategy (e.g., constant fan vs. AUTO fan), fan type, fan motor efficiency and pressure losses through the air distribution system. Therefore, this DX system model does not account for the thermal effects or electric power consumption of the indoor supply air fan. EnergyPlus contains separate models for simulating the performance of various indoor fan configurations, and these models can be easily linked with the DX system model described here to simulate the entire DX system being considered. For the time being, this coil model can only be called by the parent object UnitarySystem:MultiSpeedHeatPump:AirToAir.

When the model determines performance at Speed 1 (the lowest speed) or cycling between OFF and Speed 1, its performance is almost the same as the performance for the Coil:DX:HeatingEmpirical model. However, the outlet conditions are calculated slightly differently. Therefore, the Coil:DX:HeatingEmpirical model may be considered as a subset of the model described here. When the multispeed coil model determines performance at higher speeds (above 1), the model linearly interpolates the performance at two consecutive speeds (n-1 and n) as needed to meet the heating load, with the fraction of time at each speed established by the speed ratio.

Model Inputs

The model inputs are also very similar to the inputs of the Coil:DX:HeatingEmpirical object. The main difference is that this multispeed model requires a set of fields at each speed, such as rated capacity, rated COP, two capacity modifiers, two energy input ratio modifiers, and part-load correction. The inputs also include waste heat fraction and modifier as a function of temperature to calculate recoverable waste heat for heat recovery, which are not available in the similar Coil:DX:HeatingEmpirical object.

Speed 1 Operation

The calculation procedures in this model, including defrost and crankcase heater, are identical to the Coil:DX:HeatingEmpirical object (Ref: Coil:DX:HeatingEmpirical) with one exception: outlet node condition calculation when the supply air fan operation mode is ContFanCycComp. The following procedure provides the detailed description of the exception.

- Total delivered heating capacity

The total delivered heating capacity for speed 1 operating at the cycling ratio needed to meet the requested heating load is:

$$Q_{coil,cycling} = \dot{m}_{Speed1}\left(CycRatio\right)(h_{inlet} - h_{outlet,full})$$

where,

$Q_{coil,cycling}$ = delivered sensible heating capacity for Speed 1 operating at a specific cycling ratio [W]

$\dot{m}_{Speed\,1}$ = air mass flow rate through heating coil at Speed 1 as set by the parent object [kg/s]

$h_{outlet,full}$ = specific enthalpy of the coil outlet air during full-load operation at Speed 1 (no cycling) [J/kg]

h_{inlet} = specific enthalpy of the coil inlet air [J/kg]

$CycRatio$ = cycling ratio at Speed 1, ratio of requested heating load to the full-load capacity of the coil at Speed 1 [dimensionless]

It is assumed that the coil provides no heating capacity when the coil is OFF, even if the supply air fan continues to operate.

- Outlet air specific enthalpy

The average specific enthalpy of the coil outlet air is then calculated based on the delivered sensible heating capacity and the average air mass flow rate entering the coil:

$$h_{outlet,average} = h_{inlet} - Q_{coil,cycling} \Big/ \dot{m}_{inlet}$$

where,

$h_{outlet,average}$ = average specific enthalpy at the coil outlet [J/kg]

$\dot{m}_{inlet}$ = mass flow rate at the inlet to the coil as established by the parent object (Ref. UnitarySystem:MultiSpeedHeatPump:AirToAir, Mass Flow Rate Calculation). This flow rate is the average value determined by the parent object, accounting for the specified flow rate when the heating coil is ON and the specified flow rate when the heating coil is OFF for the time step being simulated.

- Outlet air temperature

The heating coil's outlet air humidity ratio equals the inlet air humidity ratio since the coil does not change the moisture content of the air. So the average outlet air temperature is calculated based on the inlet air humidity ratio and the average outlet air enthalpy using the psychrometric function PsyTdbFnHW.

The main reason for using the above approach is that outlet air conditions are calculated in the same way for all operating speeds.

The crankcase heater defined for this DX heating coil is enabled during the time that the compressor is not running for either heating or cooling. The crankcase heater power use from either heating or cooling is reported in the heating coil.

Higher Speed Operation

This section describes how higher speed operation is simulated. When the required sensible load is less than the full load sensible capacity at Speed n (Speed Number > 1), the following calculations are performed:

- Total delivered heating capacity at Speed n-1 and Speed n

$$TotCap_{n-1} = RatedCap_{n-1}\left(TotCapTempModFac_{n-1}\right)\left(TotCapFlowModFac_{n-1}\right)$$
$$TotCap_{n} = RatedCap_{n}\left(TotCapTempModFac_{n}\right)\left(TotCapFlowModFac_{n}\right)$$

where,

$TotCap_i$ = total delivered heating capacity at given temperatures and flow rates at Speed i [W]

$RatedCap_i$ = heating capacity at the rated conditions at Speed i [W]

$TotCapTempModFac_i$ = total heating capacity modifier as a function of indoor and outdoor air dry-bulb temperature at Speed i

$TotCapFlowModFac_i$ = total heating capacity modifier as a function of the ratio of the actual flow rate across the heating coil to the rated airflow rate at Speed i

i = Speed n or Speed n-1

- EIR at Speed n-1 and Speed n

$$EIR_{n-1} = RatedEIR_{n-1}\left(EIRTempModFac_{n-1}\right)\left(EIRFlowModFac_{n-1}\right)$$

$$EIR_{n} = RateEIR_{n}\left(EIRTempModFac_{n}\right)\left(EIRFlowModFac_{n}\right)$$

where,

EIR_i = energy input ratio at given temperatures and flow rates at Speed i [W]

$RatedEIR_i$ = energy input ratio at the rated conditions at Speed i [W]

$EIRTempModFac_i$ = energy input ratio modifier as a function of indoor and outdoor air dry-bulb temperature at Speed i

$EIRFlowModFac_i$ = energy input ratio modifier as a function of the ratio of the actual flow rate across the heating coil to the rated airflow rate at Speed i

i = Speed n or Speed n-1

- Full load outlet air specific enthalpy at Speed n-1 and Speed n

$$h_{outlet,full\_Speed\,n} = h_{inlet} - \left(TotCap_n * HeatingCapacityMultiplier\right) / \dot{m}_{inlet}$$

$$h_{outlet,full\_Speed\,n-1} = h_{inlet} - \left(TotCap_{n-1} * HeatingCapacityMultiplier\right) / \dot{m}_{inlet}$$

where,

$HeatingCapacityMultiplier$ = frost adjustment factor for heating capacity (See Ref. Coil:DX:HeatingEmpirical)

$h_{outlet,full\_Speed\,n}$ = specific enthalpy of the coil outlet air during full-load operation at Speed n (no cycling) [J/kg]

$h_{outlet,full\_Speed\,n-1}$ = specific enthalpy of the coil outlet air during full-load operation at Speed n-1 (no cycling) [J/kg]

- Effective total heating capacity

$$Q_{coil,SpeedRatio} = \left(SpeedRatio\right)\dot{m}_{Speed\,n}(h_{inlet} - h_{outlet,full\_Speed\,n})$$
$$+ (1 - SpeedRatio)\dot{m}_{Speed\,n-1}(h_{inlet} - h_{outlet,full\_Speed\,n-1})$$

where,

$Q_{coil,SpeedRatio}$ = delivered sensible heating capacity at a given speed ratio between two consecutive speeds [W]

$\dot{m}_{Speed\,n}$ = air mass flow rate through heating coil at Speed n as set by the parent object [kg/s]

$\dot{m}_{Speed\,n-1}$ = air mass flow rate through heating coil at Speed 1 as set by the parent object [kg/s]

- Average outlet air enthalpy

$$h_{outlet,average} = h_{inlet} - Q_{coil,SpeedRatio} / \dot{m}_{inlet}$$

where,

$h_{outlet,average}$ = average specific enthalpy at the coil outlet [J/kg]

h_{inlet} = specific enthalpy of the coil inlet air [J/kg]

$\dot{m}_{inlet}$ = Mass flow rate at the inlet to the coil as established by the parent object (Ref. UnitarySystem:MultiSpeedHeatPump:AirToAir, Mass Flow Rate Calculation). This flow rate is the average value determined by the parent object, accounting for the specified flow rate when the heating coil is at Speed n and the specified flow rate when the heating coil is at Speed n-1 for the time step being simulated.

- Average outlet air temperature

The heating coil's outlet air humidity ratio equals the inlet air humidity ratio since the coil does not change the moisture content of the air. So the average outlet air temperature is calculated based on the inlet air humidity ratio and the average outlet air enthalpy using the psychrometric function PsyTdbFnHW.

- Full load energy inputs at Speed n-1 and Speed n

$$HeatingPower_n = TotCap_n \left(EIR_n\right)\left(HeatingCapacityMultiplier\right)\left(InputPowerMultiplier\right)$$

$$HeatingPower_{n-1} = TotCap_{n-1} \left(EIR_{n-1}\right)\left(HeatingCapacityMultiplier\right)\left(InputPowerMultiplier\right)$$

where,

$InputPowerMultiplier$ = Frost adjustment factor for heating power calculation (Ref. Coil:DX:HeatingEmpirical)

- Calculate combined energy input

When the input for the field 'Apply Part Load Fraction to Speeds Greater than 1' is No (equivalent to a single compressor), the combined energy output is calculated as follows:

$$HeatingPower = HeatingPower_n \left(SpeedRatio\right) + HeatingPower_{n-1}(1.0 - SpeedRatio)$$

When the input for the field 'Apply Part Load Fraction to Speeds Greater than 1' is Yes (equivalent to multiple compressors), the combined energy output is calculated as follows:

$$HeatingPower = HeatingPower_n \left(RTF\right) + HeatingPower_{n-1}(1.0 - RTF)$$

where,

HeatingPower = Power used in Watt

RTF = Run time fraction (SpeedRatio/Part-load Fraction) at Speed n

- Calculate defrost power

When the defrost strategy is resistive, the power calculation is the same as Speed 1 operation (Ref. Coil:DX:HeatingEmpirical). When the defrost strategy is reverse-cycle, the following calculations are performed:

$$Q_{defrost,n} = 0.01(t_{frac,defrost})(7.222 - T_{db,o})\left(\frac{Q_{total,rated,n}}{1.01667}\right)$$

$$P_{defrost,n-1} = DefrostEIRTempModFac\left(\frac{Q_{total,rated,n-1}}{1.01667}\right)(t_{frac,defrost})$$

$$P_{defrost,n} = DefrostEIRTempModFac\left(\frac{Q_{total,rated,n}}{1.01667}\right)(t_{frac,defrost})$$

where,

$Q_{defrost,n}$ = additional indoor heating load due to reverse-cycle defrost at Speed n (*W*)

$Q_{total,rated,n}$ = total full-load heating capacity of the coil at rated conditions at Speed n (W)

$P_{defrost,n-1}$ = full load defrost power for the simulation time step at Speed n-1 (W)

$P_{defrost,n}$ = full load defrost power for the simulation time step at Speed n (W)

$Q_{total,rated,n-1}$ = capacity of the resistive defrost heating element at Speed n-1 (W)

$Q_{total,rated,n}$ = capacity of the resistive defrost heating element at Speed n (W)

DefrostEIRTempModFac = defrost energy input ratio (EIR) modifier curve (Ref. Coil:DX:HeatingEmpirical).

$T_{frac,defrost}$ = fractional defrost time (Ref. Coil:DX:HeatingEmpirical)

When the input for the field 'Apply Part Load Fraction to Speeds Greater than 1' is No (equivalent to a single compressor), the average defrost power is calculated as follows:

$$P_{defrost} = P_{defrost,n}(SpeedRatio) + P_{defrost,n-1}(1.0 - SpeedRatio)$$

When the input for the field 'Apply Part Load Fraction to Speeds Greater than 1' is Yes (equivalent to multiple compressors), the combined defrost energy is calculated as follows:

$$P_{defrost} = P_{defrost,n}(RTF) + P_{defrost,n-1}(1.0 - RTF)$$

where,

$P_{defrost}$ = average defrost power used in Watt

RTF = Run time fraction (SpeedRatio/Part-load Fraction) at Speed n

- Crankcase heater

There is no power need at higher speed operation.

Waste heat calculation

The waste heat generated by this coil object is calculated as:

$$Q_{WasteHeat} = (Fraction)(TempModifier)(HeatingPowe)$$

where,

Fraction = rated waste heat fraction of the energy input

TempModifier = waste heat modifier as a function of indoor and outdoor air dry-bulb temperature

Input Output Reference for Coil:DX:MultiSpeed:Cooling

This component models a DX cooling unit with multiple discrete levels of cooling capacity. Depending on input choices, the user can model a single compressor with multiple operating speeds, or a unit with a single cooling coil fed by multiple compressors (e.g., row split or intertwined coil circuiting). Currently, this cooling coil can only be referenced by a UnitarySystem:MultiSpeedHeatPump:AirToAir compound object. Refer to Coil:DX:MultiMode:CoolingEmpirical if the user wishes to model a cooling coil with discrete levels of cooling and the possibility of air bypass during low speed operation (e.g. face-split coil circuiting), or if cooling coil operation based on dehumidification requirements is desired.

The multispeed DX cooling coil can have from two to four operating speeds. When the coil operates at Speed 1 (the lowest speed), its performance is very similar to the Coil:DX:CoolingBypassFactorEmpirical object where the impacts of part-load ratio and latent capacity degradation can be included. When the coil operates at higher speeds (above Speed 1), the linear approximation methodology is applied. The coil outputs at two consecutive speeds are linearly interpolated to meet the required cooling capacity during an HVAC system time step. When the coil performs above the lowest speed, the user can chose if they want to include part-load ratio and latent capacity degradation impacts at the higher speeds.

The multispeed unit is described by specifying the performance at different operating speeds. Each speed has its own set of input specifications: full load capacity, SHR, COP and air flow rate at rated conditions, along with modifier curves to determine performance when actual operating conditions are different from the rated conditions.

The coil operates to meet the sensible capacity being requested. When this requested capacity is above the sensible capacity of the highest operating speed, the coil runs continuously at the highest speed. When the requested capacity is between the sensible capacities of two consecutive speeds, the unit will operate a portion of the time at each speed to meet the request. When the requested capacity is less than the low speed (Speed 1) capacity, the unit will cycle on/off as needed.

Field: Coil Name

A unique user-assigned name for an instance of a multispeed DX cooling coil. Any reference to this DX coil by another object will use this name.

Field: Availability Schedule

The name of the schedule (ref: Schedule) that denotes whether the DX cooling coil can run during a given hour. A schedule value greater than 0 (usually 1 is used) indicates that the unit can be on during the hour. A value less than or equal to 0 (usually 0 is used) denotes that the unit must be off for the hour.

Field: Coil Air Inlet Node

The name of the HVAC system node from which the DX cooling coil draws its inlet air.

Field: Coil Air Outlet Node

The name of the HVAC system node to which the DX cooling coil sends its outlet air.

Field: Supply Air Fan Operation Mode

This input field has 2 choices: CycFanCycComp and ContFanCycComp. The parent object UnitarySystem:MultiSpeedHeatPump:AirToAir also has an input field that defines a schedule for the supply fan operation mode. Currently, the mode defined in the parent object schedule overrides the fan operation mode defined in this field.

Field: Condenser Air Inlet Node Name

This optional alpha field specifies the outdoor air node name used to define the conditions of the air entering the outdoor condenser. If this field is left blank, the outdoor air temperature entering the condenser (dry-bulb or wet-bulb) is taken directly from the weather data. If this field is not blank, the node name specified must also be specified in an Outside Air Node object where the height of the node is taken into consideration when calculating outdoor air temperature from the weather data. Alternately, the node name may be specified in an Outside Air Inlet Node List object where the outdoor air temperature is taken directly from the weather data.

Field: Condenser Type

The type of condenser used by the multispeed DX cooling coil. Valid choices for this input field are Air Cooled or Evap Cooled. The default for this field is Air Cooled.

Field: Name of Water Storage Tank for Supply

This field is optional. It is used to describe where the coil obtains water used for evaporative cooling. If blank or omitted, then the evaporative cooler will obtain water directly from the mains. If the name of a Water Storage Tank object is used here, then the cooler will obtain its water from that tank. If a tank is specified, the coil will attempt to obtain all the water it uses from the tank. However if the tank cannot provide all the water the cooler needs, then the cooler will still operate and obtain the rest of the water it needs from the mains (referred to as StarvedWater).

Field: Name of Water Storage Tank for Condensate Collection

This field is optional. It is used to describe where condensate from the coil is collected. If blank or omitted, then any coil condensate is discarded. Enter the name of Water Storage Tank object defined elsewhere and the condensate will then be collected in that tank.

Field: Apply Part Load Fraction to Speeds greater than 1

This field determines whether part-load impacts on coil energy use are applied when the coil is operating at speeds greater than speed 1. The allowed choices are Yes or No, with the default being No if this field is left blank. Other input fields in this object allow the user to specify a part-load fraction correlation for each speed to account for compressor start up losses (cycle on/off). For the case of a single multi-speed compressor, the part load losses may only be significant when the compressor cycles between speed 1 and off, but the losses may be extremely small when the compressor operates between speed 1 and speed 2 (or between speeds 2 and 3, etc.). In this case, the user may chose to specify NO for this input field to neglect part-load impacts on energy use at higher operating speeds. If part-load impacts on coil energy use are thought to be significant (e.g., interwined cooling coil with multiple compressors feeding individual refrigerant circuits), then the user may chose to specify YES and the part-load fraction correlations specified for speeds 2 through 4 will be applied as appropriate. The selection for this input field does not affect part-load impacts when the compressor cycles between speed 1 and off (i.e., the part-load fraction correlation for speed 1 is always applied).

Field: Apply Latent Degradation to Speeds greater than 1

This field determines whether latent capacity degradation is applied when the coil is operating at speeds greater than speed 1. The allowed choices are Yes or No, with the default being No if this field is left blank. Other input fields in this object allow the user to specify latent capacity degradation at each speed.

The latent capacity degradation model only applies when the ContFanCycComp supply air fan operating mode is specified, to account for moisture evaporation from the wet cooling coil when the compressor cycles off but the supply air fan continues to operate. For the case of a single multi-speed compressor, latent capacity degradation may only be significant when the compressor cycles between speed 1 and off, but the losses may be extremely small when the compressor operates between speed 1 and speed 2 (or between speeds 2 and 3, etc.). In this case, the user may chose to specify NO for this input field to neglect latent capacity degradation impacts at higher operating speeds. If latent capacity degradation is thought to be significant (e.g., intertwined or row-split cooling coil with multiple compressors feeding individual refrigerant circuits), then the user may chose to specify YES and the latent capacity degradation model will be applied for speeds 2 through 4 as appropriate. The selection for this input field does not affect latent capacity degradation between speed 1 and off.

Field: Crankcase Heater Capacity

This numeric field defines the crankcase heater capacity in Watts. When the outdoor air dry-bulb temperature is below the value specified in the input field “Maximum Outdoor Dry-bulb Temperature for Crankcase Heater Operation” (described below), the crankcase heater is enabled during the time that the compressor is not running. The value for this input field must be greater than or equal to 0. If this input field is left blank, the default value is 0. To simulate a unit without a crankcase heater, enter a value of 0.

Field: Maximum Outdoor Dry-bulb Temperature for Crankcase Heater Operation

This numeric field defines the outdoor air dry-bulb temperature above which the compressor’s crankcase heater is disabled. The value for this input field must be greater than or equal to 0.0°C. If this input field is left blank, the default value is 10°C.

Field: Fuel Type

This alpha field determines the type of fuel that this cooling coil uses. This field has seven choices: Electricity, NaturalGas, PropaneGas, Diesel, Gasoline, FuelOil#1, and FuelOil#2. The default is NaturalGas.

Field: Number of speeds

This field specifies the number of sets of data being entered for rated specifications, performance curves, evaporative condenser data, latent degradation data, and waste heat specifications for each cooling speed. The rated specifications consist of rated capacity, rated SHR, rated COP, and rated air flow rate. The performance curves consist of a total capacity modifier curve as a function of temperature, total capacity modifier curve as a function of flow fraction, energy input ratio modifier curve as a function of temperature, energy input ratio modifier curve as a function of flow fraction, and part load fraction correlation as a function of part load ratio. The evaporative condenser data consists of effectiveness, condenser air volume flow rate, and rated pump power consumption. The latent degradation data consists of nominal time for condensate removal to begin, ratio of initial moisture evaporation rate and steady-state latent capacity, maximum On/Off cycling rate, and latent capacity time constant. The latent degradation data are only applied if the supply air fan operation mode is specified as ContFanCycComp. The waste heat specifications include the fraction of energy input to the cooling coil at the fully loaded and rated conditions, and a temperature modifier. The minimum number of speeds for cooling is 2 and the maximum number is 4. The number of speeds should be the same as the number of speeds for cooling defined in its parent object (UnitarySystem:MultiSpeedHeatPump: AirToAir). The first set of performance inputs is for Speed 1 and should be for low speed, and the last set of performance inputs should be for high speed. For example, if only three cooling speeds are defined, the first set should be for low speed (Speed 1), the second set should be for medium speed (Speed 2), and the third set should be for high speed (Speed 3). In this example, any performance inputs for Speed 4 would be neglected (since this input field specifies that the coil only has three cooling speeds).

Field Group: rated specification, performance curves, latent capacity degradation inputs, and evaporative cooled condenser data

The performance for each cooling speed must be specified as shown below. All inputs for Speed 1 are required first, followed by the inputs for Speed 2, Speed 3 and Speed 4.

Field: Rated Total Cooling Capacity, Speed 1 (gross)

The total, full load cooling capacity (sensible plus latent) in watts of the DX coil unit for Speed 1 operation at rated conditions (air entering the cooling coil at 26.7°C drybulb/19.4°C wetbulb, air entering the outdoor condenser coil at 35°C drybulb/23.9°C wetbulb[1], and a cooling coil air flow rate defined by field "Rated Air Volume Flow Rate, Speed 1" below). Capacity should be "gross" (i.e., supply air fan heat is NOT included).

Field: Rated SHR, Speed 1

The sensible heat ratio (sensible capacity divided by total cooling capacity) of the DX cooling coil for Speed 1 operation at rated conditions (air entering the cooling coil at 26.7°C drybulb/19.4°C wetbulb, air entering the outdoor condenser coil at 35°C drybulb/23.9°C wetbulb, and a cooling coil air flow rate defined by field "Rated Air Volume Flow Rate, Speed 1" below). Both the sensible and total cooling capacities used to define the Rated SHR should be "gross" (i.e., supply air fan heat is NOT included).

Field: Rated COP, Speed 1

The coefficient of performance (cooling power output in watts divided by electrical power input in watts) of the DX cooling coil unit for Speed 1 operation at rated conditions (air entering the cooling coil at 26.7°C drybulb/19.4°C wetbulb, air entering the outdoor condenser coil at 35°C drybulb/23.9°C wetbulb, and a cooling coil air flow rate defined by field "Rated Air Volume Flow Rate, Speed 1" below). The input power includes power for the compressor(s) and condenser fan(s) but does not include the power consumption of the supply air fan. The cooling power output is the value entered above in the field "Rated Total Cooling Capacity, Speed 1 (gross)". If this input field is left blank, the default value is 3.0.

Field: Rated Air Volume Flow Rate, Speed 1

The volumetric air flow rate for Speed 1, in m^3 per second, across the DX cooling coil at rated conditions. The rated air volume flow rate for Speed 1 should be between

[1] The 23.9°C wet-bulb temperature condition is not applicable for air-cooled condensers which do not evaporate condensate.

0.00004027 m^3/s and 0.00006041 m^3/s per watt of rated total cooling capacity for Speed 1. The rated total cooling capacity, rated SHR and rated COP for Speed 1 should be performance information for the unit with air entering the cooling coil at 26.7°C drybulb/19.4°C wetbulb, air entering the outdoor condenser coil at 35°C drybulb/23.9°C wetbulb, and the rated air volume flow rate defined here.

Field: Total Cooling Capacity Modifier Curve, Speed 1 (function of temperature)

The name of a biquadratic performance curve (ref: Performance Curves) that parameterizes the variation of the total cooling capacity for Speed 1 as a function of the wet-bulb temperature of the air entering the cooling coil, and the dry-bulb temperature of the air entering the air-cooled condenser (wet-bulb temperature if modeling an evaporative-cooled condenser). The output of this curve is multiplied by the rated total cooling capacity for Speed 1 to give the total cooling capacity at specific temperature operating conditions (i.e., at temperatures different from the rating point temperatures). The curve is normalized to have the value of 1.0 at the rating point.

Field: Total Cooling Capacity Modifier Curve, Speed 1 (function of flow fraction)

The name of a quadratic performance curve (ref: Performance Curves) that parameterizes the variation of total cooling capacity for Speed 1 as a function of the ratio of actual air flow rate across the cooling coil to the rated air flow rate for Speed 1 (i.e., fraction of full load flow). The output of this curve is multiplied by the rated total cooling capacity and the total cooling capacity modifier curve (function of temperature) to give the total cooling capacity for Speed 1 at the specific temperature and air flow conditions at which the coil is operating. The curve is normalized to have the value of 1.0 when the actual air flow rate equals the rated air flow rate for Speed 1.

Field: Energy Input Ratio Modifier Curve, Speed 1 (function of temperature)

The name of a biquadratic performance curve (ref: Performance Curves) that parameterizes the variation of the energy input ratio (EIR) for Speed 1 as a function of the wetbulb temperature of the air entering the cooling coil and the drybulb temperature of the air entering the air-cooled condenser (wetbulb temperature if modeling an evaporative-cooled condenser). The EIR is the inverse of the COP. The output of this curve is multiplied by the rated EIR for Speed 1 (inverse of rated COP for Speed 1) to give the EIR for Speed 1 at specific temperature operating conditions (i.e., at temperatures different from the rating point temperatures). The curve is normalized to a value of 1.0 at the rating point.

Field: Energy Input Ratio Modifier Curve, Speed 1 (function of flow fraction)

The name of a quadratic performance curve (Ref: Performance Curves) that parameterizes the variation of the energy input ratio (EIR) for Speed 1 as a function of the ratio of actual air flow rate across the cooling coil to the rated air flow rate for Speed 1 (i.e., fraction of full load flow). The EIR is the inverse of the COP. The output of this curve is multiplied by the rated EIR and the EIR modifier curve (function of temperature) to give the EIR for Speed 1 at the specific temperature and air flow conditions at which the cooling coil is operating. This curve is normalized to a value of 1.0 when the actual air flow rate equals the rated air flow rate for Speed 1.

Field: Part Load Fraction Correlation, Speed 1 (function of part load ratio)

This alpha field defines the name of a quadratic or cubic performance curve (Ref: Performance Curves) that parameterizes the variation of electrical power input to the DX unit as a function of the part load ratio (PLR, sensible cooling load/steady-state sensible cooling capacity for Speed 1). The product of the rated EIR and EIR modifier curves is divided by the output of this curve to give the “effective” EIR for a given simulation time step for Speed 1. The part load fraction (PLF) correlation accounts for efficiency losses due to compressor cycling.

The part load fraction correlation should be normalized to a value of 1.0 when the part load ratio equals 1.0 (i.e., no efficiency losses when the compressor(s) run continuously for the simulation time step). For PLR values between 0 and 1 (0 <= PLR < 1), the following rules apply:

PLF >= 0.7 and PLF >= PLR

If PLF < 0.7 a warning message is issued, the program resets the PLF value to 0.7, and the simulation proceeds. The runtime fraction of the coil is defined as PLR/PLF. If PLF < PLR, then a warning message is issued and the runtime fraction of the coil is limited to 1.0.

A typical part load fraction correlation for a conventional DX cooling coil (Speed 1) would be:

PLF = 0.85 + 0.15(PLR)

If the user wishes to model no efficiency degradation due to compressor cycling, the part load fraction correlation should be defined as follows:

PLF = 1.0 + 0.0(PLR)

Field: Nominal Time for Condensate Removal to Begin, Speed 1

For Speed 1, the nominal time (in seconds) after startup for condensate to begin leaving the coil's condensate drain line at the coil's rated airflow and temperature conditions, starting with a dry coil. Nominal time is equal to the ratio of the energy of the coil's maximum condensate holding capacity (J) to the coil's steady-state latent capacity (W). Suggested value is 1000; zero value means the latent degradation model is disabled. The default value for this field is zero. The field Supply Air Fan Operation Mode must be “ContFanCycComp”, and this field as well as the next three input fields for this object must have positive values in order to model latent capacity degradation for Speed 1.

Field: Ratio of Initial Moisture Evaporation Rate and Steady-state Latent Capacity, Speed 1

For Speed 1, the ratio of the initial moisture evaporation rate from the cooling coil (when the compressor first turns off, in Watts) and the coil's steady-state latent capacity (Watts) for Speed 1 at rated airflow and temperature conditions. Suggested value is 1.5; zero value means the latent degradation model is disabled. The default value for this field is zero. The field Supply Air Fan Operation Mode must be “ContFanCycComp”; and this field, the previous field and the next two fields must have positive values in order to model latent capacity degradation for Speed 1.

Field: Maximum ON/OFF Cycling Rate, Speed 1

For Speed 1, the maximum on-off cycling rate for the compressor (cycles per hour), which occurs at 50% run time fraction. Suggested value is 3; zero value means latent degradation model is disabled. The default value for this field is zero. The field Supply Air Fan Operation Mode must be “ContFanCycComp”; and this field, the previous two fields and the next field must have positive values in order to model latent capacity degradation for Speed 1.

Field: Latent Capacity Time Constant, Speed 1

For Speed 1, the time constant (in seconds) for the cooling coil's latent capacity to reach steady state after startup. Suggested value is 45; zero value means latent degradation model is disabled. The default value for this field is zero. The field Supply Air Fan Operation Mode must be “ContFanCycComp”, and this field as well as the previous three input fields for this object must have positive values in order to model latent capacity degradation for Speed 1.

Field: Rated waste heat fraction of power input, Speed 1

The fraction of energy input to the cooling coil that is available as recoverable waste heat at full load and rated conditions for Speed 1.

Field: Waste heat modifier curve, Speed 1 (function of temperature)

The name of a bi-quadratic performance curve (ref: Performance Curves) that parameterizes the variation of the waste heat recovery as a function of outdoor dry-bulb temperature and the entering coil dry-bulb temperature at Speed 1. The output of this curve is multiplied by the rated waste heat fraction at specific temperature operating conditions (i.e., at temperatures different from the rating point). The curve is normalized to a value of 1.0 at the rating point. When the fuel type is electricity, this field can remain blank since it is ignored by the program in this instance.

Field: Evaporative Condenser Effectiveness, Speed 1

The effectiveness of the evaporative condenser at Speed 1, which is used to determine the temperature of the air entering the outdoor condenser coil as follows:

$$T_{cond\,inlet} = \left(T_{wb,o}\right) + \left(1 - EvapCondEffectiveness_{Speed1}\right)\left(T_{db,o} - T_{wb,o}\right)$$

where

$T_{cond\ inlet}$ = the temperature of the air entering the condenser coil (C)

$T_{wb,o}$ = the wet-bulb temperature of the outdoor air (C)

$T_{db,o}$ = the dry-bulb temperature of the outdoor air (C)

The resulting condenser inlet air temperature is used by the Total Cooling Capacity Modifier Curve, Speed 1 (function of temperature) and the Energy Input Ratio Modifier Curve, Speed 1 (function of temperature). The default value for this field is 0.9, although valid entries can range from 0.0 to 1.0. This field is not used when Condenser Type = Air Cooled.

If the user wants to model an air-cooled condenser, they should simply specify AIR COOLED in the field Condenser Type. In this case, the Total Cooling Capacity Modifier Curve, Speed 1 (function of temperature) and the Energy Input Ratio Modifier Curve, Speed 1 (function of temperature) input fields for this object should reference performance curves that are a function of outdoor dry-bulb temperature.

If the user wishes to model an evaporative-cooled condenser AND they have performance curves that are a function of the wet-bulb temperature of air entering the condenser coil, then the user should specify Condenser Type = Evap Cooled and the evaporative condenser effectiveness value should be entered as 1.0. In this case, the Total Cooling Capacity Modifier Curve, Speed 1 (function of temperature) and the Energy Input Ratio Modifier Curve, Speed 1 (function of temperature) input fields for this object should reference performance curves that are a function of the wet-bulb temperature of air entering the condenser coil.

If the user wishes to model an air-cooled condenser that has evaporative media placed in front of it to cool the air entering the condenser coil, then the user should specify Condenser Type = Evap Cooled. The user must also enter the appropriate evaporative effectiveness for the media. In this case, the Total Cooling Capacity Modifier Curve, Speed 1 (function of temperature) and the Energy Input Ratio Modifier Curve, Speed 1 (function of temperature) input fields for this object should reference performance curves that are a function of outdoor dry-bulb temperature. Be aware that the evaporative media will significantly reduce the dry-bulb temperature of the air entering the condenser coil, so the Total Cooling Capacity and EIR Modifier Curves for Speed 1 must be valid for the expected range of dry-bulb temperatures that will be entering the condenser coil.

Field: Evaporative Condenser Air Volume Flow Rate, Speed 1

The air volume flow rate, in m^3 per second, entering the evaporative condenser at Speed 1. This value is used to calculate the amount of water used to evaporatively cool the condenser inlet air. The minimum value for this field must be greater than zero, and this input field is autosizable (equivalent to 0.000114 m^3/s per watt of rated total cooling capacity for Speed 1 [850 cfm/ton]). This field is not used when Condenser Type = Air Cooled.

Field: Evaporative Condenser Pump Rated Power Consumption, Speed 1

The rated power of the evaporative condenser water pump in Watts at Speed 1. This value is used to calculate the power required to pump the water used to evaporatively cool the condenser inlet air. The default value for this input field is zero, but it is autosizable (equivalent to 0.004266 W per watt [15 W/ton] of rated total capacity for Speed 1). This field is not used when Condenser Type = Air Cooled.

- reduced for brevity --

Field: Rated Total Cooling Capacity, Speed n (gross)

The total, full load cooling capacity (sensible plus latent) in watts of the DX coil unit for Speed n operation at rated conditions (air entering the cooling coil at 26.7°C drybulb/19.4°C wetbulb, air entering the outdoor condenser coil at 35°C drybulb/23.9°C wetbulb, and a cooling coil air flow rate defined by field "Rated Air Volume Flow Rate, Speed n" below). Capacity should be "gross" (i.e., supply air fan heat is NOT included).

Field: Rated SHR, Speed n

The sensible heat ratio (sensible capacity divided by total cooling capacity) of the DX cooling coil for Speed n operation at rated conditions (air entering the cooling coil at 26.7°C drybulb/19.4°C wetbulb, air entering the outdoor condenser coil at 35°C drybulb/23.9°C wetbulb, and a cooling coil air flow rate defined by field "Rated Air Volume Flow Rate, Speed n" below). Both the sensible and total cooling capacities used to define the Rated SHR should be "gross" (i.e., supply air fan heat is NOT included).

Field: Rated COP, Speed n

The coefficient of performance (cooling power output in watts divided by electrical power input in watts) of the DX cooling coil unit for Speed n operation at rated conditions (air entering the cooling coil at 26.7°C drybulb/19.4°C wetbulb, air entering the outdoor condenser coil at 35°C drybulb/23.9°C wetbulb, and a cooling coil air flow rate defined by field "Rated Air Volume Flow Rate, Speed n" below). The input power includes electric power for the compressor(s) and condenser fan(s) but does not include the power consumption of the supply air fan. The cooling power output is the value entered above in the field "Rated Total Cooling Capacity, Speed n (gross)". If this input field is left blank, the default value is 3.0.

Field: Rated Air Volume Flow Rate, Speed n

The air volume flow rate for Speed n, in m^3 per second, across the DX cooling coil at rated conditions. The rated air volume flow rate for Speed n should be between 0.00004027 m^3/s and 0.00006041 m^3/s per watt of rated total cooling capacity for Speed n. The rated total cooling capacity, rated SHR and rated COP for Speed n should be performance information for the unit with air entering the cooling coil at 26.7°C drybulb/19.4°C wetbulb, air entering the outdoor condenser coil at 35°C drybulb/23.9°C wetbulb, and the rated air volume flow rate defined here.

Field: Total Cooling Capacity Modifier Curve Speed n (function of temperature)

The name of a bi-quadratic performance curve (ref: Performance Curves) that parameterizes the variation of the total cooling capacity for Speed n as a function of the wet-bulb temperature of the air entering the cooling coil, and the dry-bulb temperature of the air entering the air-cooled condenser (wet-bulb temperature if modeling an evaporative-cooled condenser). The output of this curve is multiplied by the rated total cooling capacity for Speed n to give the total cooling capacity for Speed n at specific temperature operating conditions (i.e., at temperatures different from the rating point temperatures). The curve is normalized to have the value of 1.0 at the rating point.

Field: Total Cooling Capacity Modifier Curve, Speed n (function of flow fraction)

The name of a quadratic performance curve (ref: Performance Curves) that parameterizes the variation of total cooling capacity for Speed n as a function of the ratio of actual air flow rate across the cooling coil to the rated air flow rate for Speed n (i.e., fraction of full load flow). The output of this curve is multiplied by the rated total cooling capacity for Speed n and the total cooling capacity modifier curve for Speed n (function of temperature) to give the total cooling capacity for Speed n at the specific temperature and air flow conditions at which the coil is operating. The curve is normalized to have the value of 1.0 when the actual air flow rate equals the rated air flow rate for Speed n.

Field: Energy Input Ratio Modifier Curve, Speed n (function of temperature)

The name of a bi-quadratic performance curve (ref: Performance Curves) that parameterizes the variation of the energy input ratio (EIR) for Speed n as a function of the wet-bulb temperature of the air entering the cooling coil and the dry-bulb temperature of the air entering the air-cooled condenser (wet-bulb temperature if modeling an evaporative-cooled condenser). The EIR is the inverse of the COP. The output of this curve is multiplied by the rated EIR for Speed n (inverse of rated COP for Speed n) to give the EIR for Speed n at specific temperature operating conditions (i.e., at temperatures different from the rating point temperatures). The curve is normalized to a value of 1.0 at the rating point.

Field: Energy Input Ratio Modifier Curve, Speed n (function of flow fraction)

The name of a quadratic performance curve (Ref: Performance Curves) that parameterizes the variation of the energy input ratio (EIR) for Speed n as a function of the ratio of actual air flow rate across the cooling coil to the rated air flow rate for Speed n (i.e., fraction of full load flow). The EIR is the inverse of the COP. The output of this curve is multiplied by the rated EIR for Speed n and the EIR modifier curve for Speed n (function of temperature) to give the EIR for Speed n at the specific temperature and air flow conditions at which the cooling coil is operating. This curve is normalized to a value of 1.0 when the actual air flow rate equals the rated air flow rate for Speed n.

Field: Part Load Fraction Correlation, Speed n (function of part load ratio)

This alpha field defines the name of a quadratic or cubic performance curve (Ref: Performance Curves) that parameterizes the variation of electrical power input to the DX unit as a function of the part load ratio (PLR, sensible cooling load/steady-state sensible cooling capacity for Speed n). The product of the rated EIR for Speed n and EIR modifier curves for Speed n is divided by the output of this curve to give the "effective" EIR for Speed n for a given simulation time step. The part load fraction (PLF) correlation accounts for efficiency losses due to compressor cycling.

The part load fraction correlation should be normalized to a value of 1.0 when the part load ratio equals 1.0 (i.e., no efficiency losses when the compressor(s) run continuously for the simulation time step). For PLR values between 0 and 1 (0 <= PLR < 1), the following rules apply:

PLF >= 0.7 and PLF >= PLR

If PLF < 0.7 a warning message is issued, the program resets the PLF value to 0.7, and the simulation proceeds. The runtime fraction of the coil is defined as PLR/PLF. If PLF < PLR, then a warning message is issued and the runtime fraction of the coil is limited to 1.0.

A typical part load fraction correlation for a conventional, single-speed DX cooling coil (e.g., residential unit) would be:

PLF = 0.85 + 0.15(PLR)

If the user wishes to model no efficiency degradation due to compressor cycling, the part load fraction correlation should be defined as follows:

PLF = 1.0 + 0.0(PLR)

The part load fraction correlation for Speed n is only used if the field 'Apply Part Load Fraction to Speeds greater than 1" is specified as 'YES'.

Field: Nominal Time for Condensate Removal to Begin, Speed n

For Speed n, the nominal time (in seconds) after startup for condensate from Speed n compressor operation to begin leaving the coil's condensate drain line at the coil's rated airflow for Speed n and temperature conditions, starting with a dry coil. Nominal time is equal to the ratio of the energy of the coil's maximum condensate holding capacity (J) to the coil's steady-state latent capacity (W). Suggested value is 1000; zero value means the latent degradation model is disabled. The default value for this field is zero. The field Supply Air Fan Operation Mode must be "ContFanCycComp", and this field as well as the next three input fields for this object must have positive values in order to model latent capacity degradation for Speed n. In addition, latent capacity degradation for Speed n is only modeled if the field 'Apply Latent Degradation to Speeds greater than 1' is specified as 'YES'.

Field: Ratio of Initial Moisture Evaporation Rate and Steady-state Latent Capacity, Speed n

For Speed n, the ratio of the initial moisture evaporation rate from the cooling coil (when the coil first switches from Speed n to Speed n-1, in Watts) and the coil's steady-state latent capacity at Speed n (Watts) at rated airflow and temperature conditions. Suggested value is 1.5; zero value means the latent degradation model is disabled. The default value for this field is zero. The field Supply Air Fan Operation Mode must be "ContFanCycComp"; and this field, the previous field and the next two fields must have positive values in order to model latent capacity degradation for Speed n. In addition, latent capacity degradation for Speed n is only modeled if the field 'Apply Latent Degradation to Speeds greater than 1' is specified as 'YES'.

Field: Maximum ON/OFF Cycling Rate, Speed n

For Speed n, the maximum on-off cycling rate for the compressor (cycles per hour), which occurs at 50% run time fraction. Suggested value is 3; zero value means latent degradation model is disabled. The default value for this field is zero. The field Supply Air Fan Operation Mode must be "ContFanCycComp"; and this field, the previous two fields and the next field must have positive values in order to model latent capacity degradation for Speed n. In addition, latent capacity degradation for Speed n is only modeled if the field 'Apply Latent Degradation to Speeds greater than 1' is specified as 'YES'.

Field: Latent Capacity Time Constant, Speed n

For Speed n, the time constant (in seconds) at Speed n for the cooling coil's latent capacity to reach steady state after startup. Suggested value is 45; zero value means latent degradation model is disabled. The default value for this field is zero. The field Supply Air Fan Operation Mode must be “ContFanCycComp”, and this field as well as the previous three input fields for this object must have positive values in order to model latent capacity degradation for Speed n. In addition, latent capacity degradation for Speed n is only modeled if the field ‘Apply Latent Degradation to Speeds greater than 1’ is specified as ‘YES’.

Field: Rated waste heat fraction of power input, Speed n

The fraction of energy input to the cooling coil that is available as recoverable waste heat at full load and rated conditions for Speed n.

Field: Waste heat modifier curve, Speed n (function of temperature)

The name of a bi-quadratic performance curve (ref: Performance Curves) that parameterizes the variation of the waste heat recovery as a function of outdoor dry-bulb temperature and the entering coil dry-bulb temperature at Speed n. The output of this curve is multiplied by the rated waste heat fraction at specific temperature operating conditions (i.e., at temperatures different from the rating point). The curve is normalized to a value of 1.0 at the rating point.

Field: Evaporative Condenser Effectiveness, Speed n

The effectiveness of the evaporative condenser at Speed n, which is used to determine the temperature of the air entering the outdoor condenser coil as follows:

$$T_{cond\,inlet} = \left(T_{wb,\,o}\right) + \left(1 - EvapCondEffectiveness_{Speed\ n}\right)\left(T_{db,\,o} - T_{wb,\,o}\right)$$

where

$T_{cond\ inlet}$ = the temperature of the air entering the condenser coil (C)

$T_{wb,o}$ = the wet-bulb temperature of the outdoor air (C)

$T_{db,o}$ = the dry-bulb temperature of the outdoor air (C)

The resulting condenser inlet air temperature is used by the Total Cooling Capacity Modifier Curve, Speed n (function of temperature) and the Energy Input Ratio Modifier Curve, Speed n (function of temperature). The default value for this field is 0.9, although valid entries can range from 0.0 to 1.0. This field is not used when Condenser Type = Air Cooled.

If the user wants to model an air-cooled condenser, they should simply specify AIR COOLED in the field Condenser Type. In this case, the Total Cooling Capacity Modifier Curve, Speed n (function of temperature) and the Energy Input Ratio Modifier Curve, Speed n (function of temperature) input fields for this object should reference performance curves that are a function of outdoor dry-bulb temperature.

If the user wishes to model an evaporative-cooled condenser AND they have performance curves that are a function of the wet-bulb temperature of air entering the condenser coil, then the user should specify Condenser Type = Evap Cooled and the evaporative condenser effectiveness value should be entered as 1.0. In this case, the Total Cooling Capacity Modifier Curve, Speed n (function of temperature) and the Energy Input Ratio Modifier Curve, Speed n (function of temperature) input fields for this object should reference performance curves that are a function of the wet-bulb temperature of air entering the condenser coil.

If the user wishes to model an air-cooled condenser that has evaporative media placed in front of it to cool the air entering the condenser coil, then the user should specify Condenser Type = Evap Cooled. The user must also enter the appropriate evaporative effectiveness for the media. In this case, the Total Cooling Capacity Modifier Curve, Speed n (function of temperature) and the Energy Input Ratio

Modifier Curve, Speed n (function of temperature) input fields for this object should reference performance curves that are a function of outdoor dry-bulb temperature. Be aware that the evaporative media will significantly reduce the dry-bulb temperature of the air entering the condenser coil, so the Total Cooling Capacity and EIR Modifier Curves for Speed n must be valid for the expected range of dry-bulb temperatures that will be entering the condenser coil.

Field: Evaporative Condenser Air Volume Flow Rate, Speed n

The air volume flow rate, in m^3 per second, entering the evaporative condenser at Speed n. This value is used to calculate the amount of water used to evaporatively cool the condenser inlet air. The minimum value for this field must be greater than zero, and this input field is autosizable (equivalent to 0.000144 m^3/s per watt of the rated total cooling capacity for Speed n [850 cfm/ton]). This field is not used when Condenser Type = Air Cooled.

Field: Evaporative Condenser Pump Rated Power Consumption, Speed n

The rated power of the evaporative condenser water pump in Watts at Speed n. This value is used to calculate the power required to pump the water used to evaporatively cool the condenser inlet air. The default value for this input field is zero, but it is autosizable (equivalent to 0.004266 W per watt [15 W/ton] of the rated total cooling capacity for Speed n). This field is not used when Condenser Type = Air Cooled.

Below is the input data dictionary description for the Coil:DX:MultiSpeed:Cooling object.

```
Coil:DX:MultiSpeed:Cooling,
  \min-fields 51
  A1 , \field Coil Name
       \required-field
       \type alpha
       \reference CoolingCoilsDX
  A2 , \field Availability Schedule
       \required-field
       \type object-list
       \object-list ScheduleNames
  A3 , \field Coil Air Inlet Node
       \required-field
       \type alpha
  A4 , \field Coil Air Outlet Node
       \required-field
       \type alpha
  A5 , \field Supply Air Fan Operation Mode
       \required-field
       \type choice
       \key CycFanCycComp
       \key ContFanCycComp
  A6 , \field Condenser Air Inlet Node Name
       \type alpha
       \note Enter the name of an outdoor air node. This node name is also specified in
       \note an Outside Air Node or Outside Air Inlet Node List object.
  A7 , \field Condenser Type
       \type choice
       \key AIR COOLED
       \key EVAP COOLED
       \default AIR COOLED
  A8 , \field Name of Water Storage Tank for Supply
       \type object-list
       \object-list WaterStorageTankNames
  A9 , \field Name of Water Storage Tank for Condensate Collection
       \type object-list
       \object-list WaterStorageTankName
  A10, \field Apply Part Load Fraction to Speeds greater than 1
       \type choice
       \key Yes
       \key No
       \default No
  A11, \field Apply Latent Degradation to Speeds greater than 1
       \type choice
       \key Yes
       \key No
       \default No
  N1 , \field Crankcase Heater Capacity
       \type real
       \minimum 0.0
       \default 0.0
       \units W
       \ip-units W
  N2 , \field Maximum Outdoor Dry-bulb Temperature for Crankcase Heater Operation
       \type real
       \minimum 0.0
       \default 10.0
       \units C
  A12, \field Fuel Type
       \type choice
       \key Electricity
       \key NaturalGas
       \key PropaneGas
       \key Diesel
       \key Gasoline
       \key FuelOil#1
       \key FuelOil#2
```

```
     \default NaturalGas
N3 , \field Number of speeds
     \required-field
     \type integer
     \minimum 2
     \maximum 4
     \note Enter the number of the following sets of data for coil capacity, SHR, COP,
     \note flow rate, and associated curves.
N4 , \field Rated Total Cooling Capacity, Speed 1 (gross)
     \required-field
     \type real
     \units W
     \minimum> 0.0
     \autosizable
     \note Gross capacity excluding supply air fan heat
     \note Rating point: air entering the cooling coil at 26.7 C drybulb/19.4 C wetbulb, and
     \note air entering the outdoor condenser coil at 35 C drybulb/23.9 C wetbulb
     \note Speed 1 is defined as low speed
N5 , \field Rated SHR, Speed 1
     \required-field
     \type real
     \minimum 0.5
     \maximum 1.0
     \autosizable
     \note Rated sensible heat ratio (gross sensible capacity/gross total capacity)
     \note Sensible and total capacities do not include supply fan heat
N6 , \field Rated COP, Speed 1
     \type real
     \minimum> 0.0
     \default 3.0
     \note Does not include supply fan heat or supply fan electrical energy input
N7 , \field Rated Air Volume Flow Rate, Speed 1
     \required-field
     \type real
     \units m3/s
     \minimum> 0.0
     \autosizable
     \note Volume flow rate corresponding to Rated total cooling capacity, Rated SHR and Rated
     \note COP should be between 0.00004027 m3/s and .00006041 m3/s per watt of rated total
     \note cooling capacity
A13, \field Total Cooling Capacity Modifier Curve Speed 1 (function of temperature)
     \required-field
     \type object-list
     \object-list BiquadraticCurves
     \note curve = a + b*wb + c*wb**2 + d*edb + e*edb**2 + f*wb*edb
     \note wb = entering wetbulb temperature (C)
     \note edb = drybulb temperature seen by the condenser (C)
A14, \field Total Cooling Capacity Modifier Curve Speed 1 (function of flow fraction)
     \required-field
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*ff + c*ff**2
     \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
     \note ff = fraction of the full load flow
A15, \field Energy Input Ratio Modifier Curve Speed 1 (function of temperature)
     \required-field
     \type object-list
     \object-list BiquadraticCurves
     \note curve = a + b*wb + c*wb**2 + d*edb + e*edb**2 + f*wb*edb
     \note wb = entering wetbulb temperature (C)
     \note edb = drybulb temperature seen by the condenser (C)
A16, \field Energy Input Ratio Modifier Curve Speed 1 (function of flow fraction)
     \required-field
     \type object-list
     \object-list Quadratic_CubicCurves
     \note quadratic curve = a + b*ff + c*ff**2
     \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
     \note ff = fraction of the full load flow
A17, \field Part Load Fraction Correlation Speed 1 (function of part load ratio)
     \required-field
     \type object-list
```

```
      \object-list Quadratic_CubicCurves
      \note quadratic curve = a + b*PLR + c*PLR**2
      \note cubic curve = a + b*PLR + c*PLR**2 + d*PLR**3
      \note PLR = part load ratio (cooling load/steady-state capacity)
  N8 , \field Nominal Time for Condensate Removal to Begin, Speed 1
      \type real
      \units s
      \minimum 0.0
      \maximum 3000.0
      \default 0.0
      \note The nominal time for condensate to begin leaving the coil's condensate
      \note drain line at the coil's rated airflow and temperature conditions.
      \note Nominal time is equal to the ratio of the energy of the coil's maximum
      \note condensate holding capacity (J) to the coil's steady-state latent capacity (W).
      \note Suggested value is 1000; zero value means latent degradation model is disabled.
  N9 , \field Ratio of Initial Moisture Evaporation Rate and Steady-state Latent Capacity, Speed 1
      \type real
      \units dimensionless
      \minimum 0.0
      \maximum 5.0
      \default 0.0
      \note Ratio of the initial moisture evaporation rate from the cooling coil (when
      \note the compressor first turns off) and the coil's steady-state latent capacity
      \note at rated airflow and temperature conditions. Suggested value is 1.5; zero value
      \note means latent degradation model is disabled.
  N10, \field Maximum ON/OFF Cycling Rate, Speed 1
      \type real
      \units cycles/hr
      \minimum 0.0
      \maximum 5.0
      \default 0.0
      \note The maximum on-off cycling rate for the compressor, which occurs at 50% run time
      \note fraction. Suggested value is 3; zero value means latent degradation
      \note model is disabled.
  N11, \field Latent Capacity Time Constant, Speed 1
      \type real
      \units s
      \minimum 0.0
      \maximum 500.0
      \default 0.0
      \note Time constant for the cooling coil's latent capacity to reach steady state after
      \note startup. Suggested value is 45; zero value means latent degradation
      \note model is disabled.
  N12, \field Rated waste heat fraction of power input, Speed 1
      \required-field
      \type real
      \units dimensionless
      \minimum> 0.0
      \maximum 1.0
      \note Recoverable waste heat at full load and rated conditions
  A18, \field Waste heat modifier curve, Speed 1 (function of temperature)
      \type alpha
      \object-list BiQuadraticCurves
      \note curve = a + b*odb + c*odb**2 + d*db + e*db**2 + f*odb*db
      \note odb = Outdoor air drybulb temperature (C)
      \note db = entering coil drybulb temperature (C)
  N13, \field Evaporative Condenser Effectiveness, Speed 1
      \type real
      \units dimensionless
      \minimum 0.0
      \maximum 1.0
      \default 0.9
  N14, \field Evaporative Condenser Air Volume Flow Rate, Speed 1
      \type real
      \units m3/s
      \minimum> 0.0
      \autosizable
      \note Used to calculate evaporative condenser water use
  N15, \field Evaporative Condenser Pump Rated Power Consumption, Speed 1
      \type real
      \units W
```

```
      \minimum 0.0
      \autosizable
      \note Rated power consumed by the evaporative condenser's water pump at high speed
 N16, \field Rated Total Cooling Capacity, Speed 2 (gross)
      \required-field
      \type real
      \units W
      \minimum> 0.0
      \autosizable
      \note Gross capacity excluding supply air fan heat
      \note Rating point: air entering the cooling coil at 26.7 C drybulb/19.4 C wetbulb, and
      \note air entering the outdoor condenser coil at 35 C drybulb/23.9 C wetbulb
 N17, \field Rated SHR, Speed 2
      \required-field
      \type real
      \minimum 0.5
      \maximum 1.0
      \autosizable
      \note Rated sensible heat ratio (gross sensible capacity/gross total capacity)
      \note Sensible and total capacities do not include supply fan heat
 N18, \field Rated COP, Speed 2
      \type real
      \minimum> 0.0
      \default 3.0
      \note Does not include supply fan heat or supply fan electrical energy input
 N19, \field Rated Air Volume Flow Rate, Speed 2
      \required-field
      \type real
      \units m3/s
      \minimum> 0.0
      \autosizable
      \note Volume flow rate corresponding to Rated total cooling capacity, Rated SHR and Rated
      \note COP should be between 0.00004027 m3/s and .00006041 m3/s per watt of rated total
      \note cooling capacity for Speed 2.
 A19, \field Total Cooling Capacity Modifier Curve Speed 2 (function of temperature)
      \required-field
      \type object-list
      \object-list BiquadraticCurves
      \note curve = a + b*wb + c*wb**2 + d*edb + e*edb**2 + f*wb*edb
      \note wb = entering wetbulb temperature (C)
      \note edb = drybulb temperature seen by the condenser (C)
 A20, \field Total Cooling Capacity Modifier Curve Speed 1 (function of flow fraction)
      \required-field
      \type object-list
      \object-list Quadratic_CubicCurves
      \note quadratic curve = a + b*ff + c*ff**2
      \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
      \note ff = fraction of the full load flow
 A21, \field Energy Input Ratio Modifier Curve Speed 2 (function of temperature)
      \required-field
      \type object-list
      \object-list BiquadraticCurves
      \note curve = a + b*wb + c*wb**2 + d*edb + e*edb**2 + f*wb*edb
      \note wb = entering wetbulb temperature (C)
      \note edb = drybulb temperature seen by the condenser (C)
 A22, \field Energy Input Ratio Modifier Curve Speed 2 (function of flow fraction)
      \required-field
      \type object-list
      \object-list Quadratic_CubicCurves
      \note quadratic curve = a + b*ff + c*ff**2
      \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
      \note ff = fraction of the full load flow
 A23, \field Part Load Fraction Correlation Speed 2 (function of part load ratio)
      \required-field
      \type object-list
      \object-list Quadratic_CubicCurves
      \note quadratic curve = a + b*PLR + c*PLR**2
      \note cubic curve = a + b*PLR + c*PLR**2 + d*PLR**3
      \note PLR = part load ratio (cooling load/steady-state capacity)
 N20, \field Nominal Time for Condensate Removal to Begin, Speed 2
      \type real
```

```
      \units s
      \minimum 0.0
      \maximum 3000.0
      \default 0.0
      \note The nominal time for condensate to begin leaving the coil's condensate
      \note drain line at the coil's rated airflow and temperature conditions.
      \note Nominal time is equal to the ratio of the energy of the coil's maximum
      \note condensate holding capacity (J) to the coil's steady-state latent capacity (W).
      \note Suggested value is 1000; zero value means latent degradation model is disabled.
 N21, \field Ratio of Initial Moisture Evaporation Rate and Steady-state Latent Capacity, Speed 2
      \type real
      \units dimensionless
      \minimum 0.0
      \maximum 5.0
      \default 0.0
      \note Ratio of the initial moisture evaporation rate from the cooling coil (when
      \note the compressor first turns off) and the coil's steady-state latent capacity
      \note at rated airflow and temperature conditions. Suggested value is 1.5; zero value
      \note means latent degradation model is disabled.
 N22, \field Maximum ON/OFF Cycling Rate, Speed 2
      \type real
      \units cycles/hr
      \minimum 0.0
      \maximum 5.0
      \default 0.0
      \note The maximum on-off cycling rate for the compressor, which occurs at 50% run time
      \note fraction. Suggested value is 3; zero value means latent degradation
      \note model is disabled.
 N23, \field Latent Capacity Time Constant, Speed 2
      \type real
      \units s
      \minimum 0.0
      \maximum 500.0
      \default 0.0
      \note Time constant for the cooling coil's latent capacity to reach steady state after
      \note startup. Suggested value is 45; zero value means latent degradation
      \note model is disabled.
 N24, \field Rated waste heat fraction of power input, Speed 2
      \required-field
      \type real
      \units dimensionless
      \minimum> 0.0
      \maximum 1.0
      \note Recoverable waste heat at full load and rated conditions
 A24, \field Waste heat modifier curve, Speed 2 (function of temperature)
      \type alpha
      \object-list BiQuadraticCurves
      \note curve = a + b*odb + c*odb**2 + d*db + e*db**2 + f*odb*db
      \note odb = Outdoor air drybulb temperature (C)
      \note db = entering coil drybulb temperature (C)
 N25, \field Evaporative Condenser Effectiveness, Speed 2
      \type real
      \units dimensionless
      \minimum 0.0
      \maximum 1.0
      \default 0.9
 N26, \field Evaporative Condenser Air Volume Flow Rate, Speed 2
      \type real
      \units m3/s
      \minimum> 0.0
      \autosizable
      \note Used to calculate evaporative condenser water use
 N27, \field Evaporative Condenser Pump Rated Power Consumption, Speed 2
      \type real
      \units W
      \minimum 0.0
      \autosizable
      \note Rated power consumed by the evaporative condenser's water pump at low speed
 N28, \field Rated Total Cooling Capacity, Speed 3 (gross)
      \type real
      \units W
```

```
      \minimum> 0.0
      \autosizable
      \note Gross capacity excluding supply air fan heat
      \note Rating point: air entering the cooling coil at 26.7 C drybulb/19.4 C wetbulb, and
      \note air entering the outdoor condenser coil at 35 C drybulb/23.9 C wetbulb
 N29, \field Rated SHR, Speed 3
      \type real
      \minimum 0.5
      \maximum 1.0
      \autosizable
      \note Rated sensible heat ratio (gross sensible capacity/gross total capacity)
      \note Sensible and total capacities do not include supply fan heat
 N30, \field Rated COP, Speed 3
      \type real
      \minimum> 0.0
      \default 3.0
      \note does not include supply fan heat or supply fan electrical energy input
 N31, \field Rated Air Volume Flow Rate, Speed 3
      \type real
      \units m3/s
      \minimum> 0.0
      \autosizable
      \note Volume flow rate corresponding to Rated total cooling capacity, Rated SHR and Rated
      \note COP should be between 0.00004027 m3/s and .00006041 m3/s per watt of rated total
      \note cooling capacity for Speed 3.
 A25, \field Total Cooling Capacity Modifier Curve Speed 3 (function of temperature)
      \type object-list
      \object-list BiquadraticCurves
      \note curve = a + b*wb + c*wb**2 + d*edb + e*edb**2 + f*wb*edb
      \note wb = entering wetbulb temperature (C)
      \note edb = drybulb temperature seen by the condenser (C)
 A26, \field Total Cooling Capacity Modifier Curve Speed 3 (function of flow fraction)
      \type object-list
      \object-list Quadratic_CubicCurves
      \note quadratic curve = a + b*ff + c*ff**2
      \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
      \note ff = fraction of the full load flow
 A27, \field Energy Input Ratio Modifier Curve Speed 3 (function of temperature)
      \type object-list
      \object-list BiquadraticCurves
      \note curve = a + b*wb + c*wb**2 + d*edb + e*edb**2 + f*wb*edb
      \note wb = entering wetbulb temperature (C)
      \note edb = drybulb temperature seen by the condenser (C)
 A28, \field Energy Input Ratio Modifier Curve Speed 3 (function of flow fraction)
      \type object-list
      \object-list Quadratic_CubicCurves
      \note quadratic curve = a + b*ff + c*ff**2
      \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
      \note ff = fraction of the full load flow
 A29, \field Part Load Fraction Correlation Speed 3 (function of part load ratio)
      \type object-list
      \object-list Quadratic_CubicCurves
      \note quadratic curve = a + b*PLR + c*PLR**2
      \note cubic curve = a + b*PLR + c*PLR**2 + d*PLR**3
      \note PLR = part load ratio (cooling load/steady-state capacity)
 N32, \field Nominal Time for Condensate Removal to Begin, Speed 3
      \type real
      \units s
      \minimum 0.0
      \maximum 3000.0
      \default 0.0
      \note The nominal time for condensate to begin leaving the coil's condensate
      \note drain line at the coil's rated airflow and temperature conditions.
      \note Nominal time is equal to the ratio of the energy of the coil's maximum
      \note condensate holding capacity (J) to the coil's steady-state latent capacity (W).
      \note Suggested value is 1000; zero value means latent degradation model is disabled.
 N33, \field Ratio of Initial Moisture Evaporation Rate and Steady-state Latent Capacity, Speed 3
      \type real
      \units dimensionless
      \minimum 0.0
      \maximum 5.0
```

```
      \default 0.0
      \note Ratio of the initial moisture evaporation rate from the cooling coil (when
      \note the compressor first turns off) and the coil's steady-state latent capacity
      \note at rated airflow and temperature conditions. Suggested value is 1.5; zero value
      \note means latent degradation model is disabled.
 N34, \field Maximum ON/OFF Cycling Rate, Speed 3
      \type real
      \units cycles/hr
      \minimum 0.0
      \maximum 5.0
      \default 0.0
      \note The maximum on-off cycling rate for the compressor, which occurs at 50% run time
      \note fraction. Suggested value is 3; zero value means latent degradation
      \note model is disabled.
 N35, \field Latent Capacity Time Constant, Speed 3
      \type real
      \units s
      \minimum 0.0
      \maximum 500.0
      \default 0.0
      \note Time constant for the cooling coil's latent capacity to reach steady state after
      \note startup. Suggested value is 45; zero value means latent degradation
      \note model is disabled.
 N36, \field Rated waste heat fraction of power input, Speed 3
      \type real
      \units dimensionless
      \minimum> 0.0
      \maximum 1.0
      \note Recoverable waste heat at full load and rated conditions
 A30, \field Waste heat modifier curve, Speed 3 (function of temperature)
      \type alpha
      \object-list BiQuadraticCurves
      \note curve = a + b*odb + c*odb**2 + d*db + e*db**2 + f*odb*db
      \note odb = Outdoor air drybulb temperature (C)
      \note db = entering coil drybulb temperature (C)
 N37, \field Evaporative Condenser Effectiveness, Speed 3
      \type real
      \units dimensionless
      \minimum 0.0
      \maximum 1.0
      \default 0.9
 N38, \field Evaporative Condenser Air Volume Flow Rate, Speed 3
      \type real
      \units m3/s
      \minimum> 0.0
      \autosizable
      \note Used to calculate evaporative condenser water use
 N39, \field Evaporative Condenser Pump Rated Power Consumption, Speed 3
      \type real
      \units W
      \minimum 0.0
      \autosizable
      \note Rated power consumed by the evaporative condenser's water pump at low speed
 N40, \field Rated Total Cooling Capacity, Speed 4 (gross)
      \type real
      \units W
      \minimum> 0.0
      \autosizable
      \note Gross capacity excluding supply air fan heat
      \note Rating point: air entering the cooling coil at 26.7 C drybulb/19.4 C wetbulb, and
      \note air entering the outdoor condenser coil at 35 C drybulb/23.9 C wetbulb
 N41, \field Rated SHR, Speed 4
      \type real
      \minimum 0.5
      \maximum 1.0
      \autosizable
      \note Rated sensible heat ratio (gross sensible capacity/gross total capacity)
      \note Sensible and total capacities do not include supply fan heat
 N42, \field Rated COP, Speed 4
      \type real
      \minimum> 0.0
```

```
      \default 3.0
      \note Does not include supply fan heat or supply fan electrical energy input
 N43, \field Rated Air Volume Flow Rate, Speed 4
      \type real
      \units m3/s
      \minimum> 0.0
      \autosizable
      \note Volume flow rate corresponding to Rated total cooling capacity, Rated SHR and Rated
      \note COP should be between 0.00004027 m3/s and .00006041 m3/s per watt of rated total
      \note cooling capacity for Speed 4
 A31, \field Total Cooling Capacity Modifier Curve Speed 4 (function of temperature)
      \type object-list
      \object-list BiquadraticCurves
      \note curve = a + b*wb + c*wb**2 + d*edb + e*edb**2 + f*wb*edb
      \note wb = entering wetbulb temperature (C)
      \note edb = drybulb temperature seen by the condenser (C)
 A32, \field Total Cooling Capacity Modifier Curve Speed 4 (function of flow fraction)
      \type object-list
      \object-list Quadratic_CubicCurves
      \note quadratic curve = a + b*ff + c*ff**2
      \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
      \note ff = fraction of the full load flow
 A33, \field Energy Input Ratio Modifier Curve Speed 4 (function of temperature)
      \type object-list
      \object-list BiquadraticCurves
      \note curve = a + b*wb + c*wb**2 + d*edb + e*edb**2 + f*wb*edb
      \note wb = entering wetbulb temperature (C)
      \note edb = drybulb temperature seen by the condenser (C)
 A34, \field Energy Input Ratio Modifier Curve Speed 4 (function of flow fraction)
      \type object-list
      \object-list Quadratic_CubicCurves
      \note quadratic curve = a + b*ff + c*ff**2
      \note cubic curve = a + b*ff + c*ff**2 + d*ff**3
      \note ff = fraction of the full load flow
 A35, \field Part Load Fraction Correlation Speed 4 (function of part load ratio)
      \type object-list
      \object-list Quadratic_CubicCurves
      \note quadratic curve = a + b*PLR + c*PLR**2
      \note cubic curve = a + b*PLR + c*PLR**2 + d*PLR**3
      \note PLR = part load ratio (cooling load/steady-state capacity)
 N44, \field Nominal Time for Condensate Removal to Begin, Speed 4
      \type real
      \units s
      \minimum 0.0
      \maximum 3000.0
      \default 0.0
      \note The nominal time for condensate to begin leaving the coil's condensate
      \note drain line at the coil's rated airflow and temperature conditions.
      \note Nominal time is equal to the ratio of the energy of the coil's maximum
      \note condensate holding capacity (J) to the coil's steady-state latent capacity (W).
      \note Suggested value is 1000; zero value means latent degradation model is disabled.
 N45, \field Ratio of Initial Moisture Evaporation Rate and Steady-state Latent Capacity, Speed 4
      \type real
      \units dimensionless
      \minimum 0.0
      \maximum 5.0
      \default 0.0
      \note Ratio of the initial moisture evaporation rate from the cooling coil (when
      \note the compressor first turns off) and the coil's steady-state latent capacity
      \note at rated airflow and temperature conditions. Suggested value is 1.5; zero value
      \note means latent degradation model is disabled.
 N46, \field Maximum ON/OFF Cycling Rate, Speed 4
      \type real
      \units cycles/hr
      \minimum 0.0
      \maximum 5.0
      \default 0.0
      \note The maximum on-off cycling rate for the compressor, which occurs at 50% run time
      \note fraction. Suggested value is 3; zero value means latent degradation
      \note model is disabled.
 N47, \field Latent Capacity Time Constant, Speed 4
```

```
      \type real
      \units s
      \minimum 0.0
      \maximum 500.0
      \default 0.0
      \note Time constant for the cooling coil's latent capacity to reach steady state after
      \note startup. Suggested value is 45; zero value means latent degradation
      \note model is disabled.
 N48, \field Rated waste heat fraction of power input, Speed 4
      \type real
      \units dimensionless
      \minimum> 0.0
      \maximum 1.0
      \note Recoverable waste heat at full load and rated conditions
 A36, \field Waste heat modifier curve, Speed 4 (function of temperature)
      \type alpha
      \object-list BiQuadraticCurves
      \note curve = a + b*odb + c*odb**2 + d*db + e*db**2 + f*odb*db
      \note odb = Outdoor air drybulb temperature (C)
      \note db = entering coil drybulb temperature (C)
 N49, \field Evaporative Condenser Effectiveness, Speed 4
      \type real
      \units dimensionless
      \minimum 0.0
      \maximum 1.0
      \default 0.9
 N50, \field Evaporative Condenser Air Volume Flow Rate, Speed 4
      \type real
      \units m3/s
      \minimum> 0.0
      \autosizable
      \note Used to calculate evaporative condenser water use
 N51; \field Evaporative Condenser Pump Rated Power Consumption, Speed 4
      \type real
      \units W
      \minimum 0.0
      \autosizable
      \note Rated power consumed by the evaporative condenser's water pump at Speed 4
```

Following is an example input for this multispeed DX cooling coil.

```
COIL:DX:MultiSpeed:Cooling,
  Heat Pump ACDXCoil 1,     !- Coil Name
  FanAndCoilAvailSched,     !- Availability Schedule
  DX Cooling Coil Air Inlet Node,  !- Coil Air Inlet Node
  Heating Coil Air Inlet Node,     !- Coil Air Outlet Node
  CycFanCycComp,            !- Supply Air Fan Operation Mode
  Outdoor Condenser Air Node,      !- Condenser Air Inlet Node Name
  AIR COOLED,               !- Condenser Type
  ,                         !- Name of Water Storage Tank for Supply
  ,                         !- Name of Water Storage Tank for Condensate Collection
  No,                       !- Apply Part Load Fraction to Speeds greater than 1
  No,                       !- Apply latent degradation to Speeds greater than 1
  200.0,                    !- Crankcase Heater Capacity {W}
  10.0,                     !- Maximum Outdoor Dry-bulb Temperature for Crankcase Heater
                            !- Operation {C}
  NaturalGas,               !- Fuel Type
  4,                        !- Number of speeds
  7500,                     !- Rated Total Cooling Capacity, Speed 1 (gross) {W}
  0.75,                     !- Rated SHR, Speed 1 {dimensionless}
  3.0,                      !- Rated COP, Speed 1 {dimensionless}
  0.40,                     !- Rated Air Volume Flow Rate, Speed 1 {m3/s}
  HPACCoolCapFT Speed 1,    !- Total Cooling Capacity Modifier Curve, Speed 1 (temperature)
  HPACCoolCapFF Speed 1,    !- Total Cooling Capacity Modifier Curve, Speed 1 (flow fraction)
  HPACCOOLEIRFT Speed 1,    !- Energy Input Ratio Modifier Curve, Speed 1 (temperature)
  HPACCOOLEIRFF Speed 1,    !- Energy Input Ratio Modifier Curve, Speed 1 (flow fraction)
  HPACCOOLPLFFPLR Speed 1,  !- Part Load Fraction Correlation, Speed 1 (part load ratio)
  1000.0,                   !- Nominal Time for Condensate Removal to Begin, Speed 1 {s}
  1.5,                      !- Ratio of Initial Moisture Evaporation Rate and Steady-state Latent
                            !- Capacity, Speed 1 {dimensionless}
  3.0,                      !- Maximum ON/OFF Cycling Rate, Speed 1 {cycles/hr}
  45.0,                     !- Latent Capacity Time Constant, Speed 1 {s}
  0.2,                      !- Rated waste heat fraction of power input, Speed 1 {dimensionless}
  HAPCCoolWHFT Speed 1,     !- Waste heat modifier curve, Speed 1 (temperature)
  0.9,                      !- Evaporative Condenser Effectiveness, Speed 1 {dimensionless}
  0.05,                     !- Evaporative Condenser Air Volume Flow Rate, Speed 1 {m3/s}
  50,                       !- Evaporative Condenser Pump Rated Power Consumption, Speed 1 {W}
  17500,                    !- Rated Total Cooling Capacity, Speed 2 (gross) {W}
  0.75,                     !- Rated SHR, Speed 2 {dimensionless}
  3.0,                      !- Rated COP, Speed 2 {dimensionless}
  0.85,                     !- Rated Air Volume Flow Rate, Speed 2 {m3/s}
  HPACCoolCapFT Speed 2,    !- Total Cooling Capacity Modifier Curve, Speed 2 (temperature)
  HPACCoolCapFF Speed 2,    !- Total Cooling Capacity Modifier Curve, Speed 2 (flow fraction)
  HPACCOOLEIRFT Speed 2,    !- Energy Input Ratio Modifier Curve, Speed 2 (temperature)
  HPACCOOLEIRFF Speed 2,    !- Energy Input Ratio Modifier Curve, Speed 2 (flow fraction)
  HPACCOOLPLFFPLR Speed 1,  !- Part Load Fraction Correlation, Speed 2 (part load ratio)
  1000.0,                   !- Nominal Time for Condensate Removal to Begin, Speed 2
  1.5,                      !- Ratio of Initial Moisture Evaporation Rate and Steady-state Latent
                            !- Capacity, Speed 2 {dimensionless}
  3.0,                      !- Maximum ON/OFF Cycling Rate, Speed 2
  45.0,                     !- Latent Capacity Time Constant, Speed 2
  0.2,                      !- Rated waste heat fraction of power input, Speed 2 {dimensionless}
  HAPCCoolWHFT Speed 2,     !- Waste heat modifier curve, Speed 2 (temperature)
  0.9,                      !- Evaporative Condenser Effectiveness, Speed 2 {dimensionless}
  0.1,                      !- Evaporative Condenser Air Volume Flow Rate, Speed 2 {m3/s}
  60,                       !- Evaporative Condenser Pump Rated Power Consumption, Speed 2 {W}
  25500,                    !- Rated Total Cooling Capacity, Speed 3 (gross) {W}
  0.75,                     !- Rated SHR, Speed 3 {dimensionless}
  3.0,                      !- Rated COP, Speed 3 {dimensionless}
  1.25,                     !- Rated Air Volume Flow Rate, Speed 3 {m3/s}
  HPACCoolCapFT Speed 3,    !- Total Cooling Capacity Modifier Curve, Speed 3 (temperature)
  HPACCoolCapFF Speed 3,    !- Total Cooling Capacity Modifier Curve, Speed 3 (flow fraction)
  HPACCOOLEIRFT Speed 3,    !- Energy Input Ratio Modifier Curve, Speed 3 (temperature)
  HPACCOOLEIRFF Speed 3,    !- Energy Input Ratio Modifier Curve, Speed 3 (flow fraction)
  HPACCOOLPLFFPLR Speed 1,  !- Part Load Fraction Correlation, Speed 3 (part load ratio)
  1000.0,                   !- Nominal Time for Condensate Removal to Begin, Speed 3 {s}
  1.5,                      !- Ratio of Initial Moisture Evaporation Rate and Steady-state Latent
                            !- Capacity, Speed 3 {dimensionless}
  3.0,                      !- Maximum ON/OFF Cycling Rate, Speed 3 {cycles/hr}
  45.0,                     !- Latent Capacity Time Constant, Speed 3 {s}
  0.2,                      !- Rated waste heat fraction of power input, Speed 3 {dimensionless}
  HAPCCoolWHFT Speed 3,     !- Waste heat modifier curve, Speed 3 (temperature)
```

```
    0.9,                     !- Evaporative Condenser Effectiveness, Speed 3 {dimensionless}
    0.2,                     !- Evaporative Condenser Air Volume Flow Rate, Speed 3 {m3/s}
    80,                      !- Evaporative Condenser Pump Rated Power Consumption, Speed 3 {W}
    35500,                   !- Rated Total Cooling Capacity, Speed 4 (gross) {W}
    0.75,                    !- Rated SHR, Speed 4 {dimensionless}
    3.0,                     !- Rated COP, Speed 4 {dimensionless}
    1.75,                    !- Rated Air Volume Flow Rate, Speed 4 {m3/s}
    HPACCoolCapFT Speed 4,   !- Total Cooling Capacity Modifier Curve, Speed 4 (temperature)
    HPACCoolCapFF Speed 4,   !- Total Cooling Capacity Modifier Curve, Speed 4 (flow fraction)
    HPACCOOLEIRFT Speed 4,   !- Energy Input Ratio Modifier Curve, Speed 4 (temperature)
    HPACCOOLEIRFF Speed 4,   !- Energy Input Ratio Modifier Curve, Speed 4 (flow fraction)
    HPACCOOLPLFFPLR Speed 1, !- Part Load Fraction Correlation, Speed 4 (part load ratio)
    1000.0,                  !- Nominal Time for Condensate Removal to Begin, Speed 4 {s}
    1.5,                     !- Ratio of Initial Moisture Evaporation Rate and Steady-state Latent
                             !- Capacity, Speed 4 {dimensionless}
    3.0,                     !- Maximum ON/OFF Cycling Rate, Speed 4 {cycles/hr}
    45.0,                    !- Latent Capacity Time Constant, Speed 4 {s}
    0.2,                     !- Rated waste heat fraction of power input, Speed 4 {dimensionless}
    HAPCCoolWHFT Speed 4,    !- Waste heat modifier curve, Speed 4 (temperature)
    0.9,                     !- Evaporative Condenser Effectiveness, Speed 4 {dimensionless}
    0.3,                     !- Evaporative Condenser Air Volume Flow Rate, Speed 4 {m3/s}
    100;                     !- Evaporative Condenser Pump Rated Power Consumption, Speed 4 {W}
```

Coil:DX:MultiSpeed:Cooling Outputs

```
HVAC,Average,DX Coil Total Cooling Rate[W]
HVAC,Sum,DX Coil Total Cooling Energy[J]
HVAC,Average,DX Coil Sensible Cooling Rate[W]
HVAC,Sum,DX Coil Sensible Cooling Energy[J]
HVAC,Average,DX Coil Latent Cooling Rate[W]
HVAC,Sum,DX Coil Latent Cooling Energy[J]
HVAC,Average,DX Cooling Coil <FuelType> Power[W]
HVAC,Sum,DX Cooling Coil <FuelType> Consumption[J]
HVAC,Average,DX Cooling Coil Runtime Fraction
HVAC,Average,DX Cooling Coil Condenser Inlet Temp [C]
HVAC,Sum,DX Cooling Coil Evap Condenser Water Consumption [m3]
HVAC,Sum,Mains water for DX Cooling Coil Evap Condenser [m3]
HVAC,Average,DX Cooling Coil Evap Condenser Pump Electric Power[W]
HVAC,Sum,DX Cooling Coil Evap Condenser Pump Electric Consumption[J]
```

DX Coil Total Cooling Rate [W]

This field is the total (sensible and latent) cooling rate output of the multispeed DX coil in Watts. This is determined by the coil inlet and outlet air conditions and the air mass flow rate through the coil.

DX Coil Total Cooling Energy [J]

This is the total (sensible plus latent) cooling output of the multispeed DX coil in Joules over the time step being reported. This is determined by the coil inlet and outlet air conditions and the air mass flow rate through the coil. This output is also added to a report meter with Resource Type = EnergyTransfer, End Use Key = CoolingCoils, Group Key = System (Ref. Report Meter).

DX Coil Sensible Cooling Rate [W]

This output is the moist air sensible cooling rate output of the multispeed DX coil in Watts. This is determined by the inlet and outlet air conditions and the air mass flow rate through the coil.

DX Coil Sensible Cooling Energy [J]

This is the moist air sensible cooling output of the multispeed DX coil in Joules for the time step being reported. This is determined by the inlet and outlet air conditions and the air mass flow rate through the coil.

DX Coil Latent Cooling Rate [W]

This is the latent cooling rate output of the multispeed DX coil in Watts. This is determined by the inlet and outlet air conditions and the air mass flow rate through the coil.

DX Coil Latent Cooling Energy [J]

This is the latent cooling output of the multispeed DX coil in Joules for the time step being reported. This is determined by the inlet and outlet air conditions and the air mass flow rate through the coil.

DX Cooling Coil <FuelType> Power [W]

This output variable is the input fuel type power for the cooling coil in Watts, averaged during the time step being reported.

DX Cooling Coil <FuelType> Consumption [J]

This output variable is the input fuel consumption for the multispeed cooling coil in the unit of Joules, summed for the time step being reported. This output is added to a report meter with Resource Type = <FuelType>, End Use Key = Cooling, Group Key = System (ref. Report Meter).

> Note: <FuelType> in the above two output variables depends on the user specified input for the Fuel Type field. In addition to Electricity, valid fuel types are NaturalGas, Propane, FuelOil#1, FuelOil#2, Coal, Diesel, and Gasoline.

DX Cooling Coil Runtime Fraction

This output variable is the cooling coil run time fraction (PLR/PLF), averaged for the time step being reported. When the cooling speed is above 1, this output is the run time fraction for the higher speed.

Cooling Coil Condenser Inlet Temp [C]

This is the inlet air temperature to the condenser coil in degrees C. This value can represent the outdoor air dry-bulb temperature, wet-bulb temperature, or somewhere in between from the weather data being used, depending on the value used in the input field “Evaporative Condenser Effectiveness”. The temperature reported here is used in the various modifier curves related to temperature (e.g., Total Cooling Capacity Modifier Curve [function of temperature]).

DX Cooling Coil Evap Condenser Water Consumption [m3]

This output is the amount of water used to evaporatively cool the condenser coil inlet air, in cubic meters. This output is also added to a report meter with Resource Type = Water, End Use Key = Cooling, Group Key = System (ref. Report Meter).

DX Cooling Coil Evap Condenser Pump Electric Power [W]

This is the average electricity consumption rate of the evaporative condenser water pump in Watts for the time step being reported.

DX Cooling Coil Evap Condenser Pump Electric Consumption [J]

This is the electricity consumption rate of the evaporative condenser water pump in Joules for the time step being reported. This output is also added to a report meter with Resource Type = Electricity, End Use Key = Cooling, Group Key = System (ref. Report Meter).

Engineering Document for Coil:DX:MultiSpeed:Cooling

Overview

This model (object name Coil:DX:MultiSpeed:Cooling) simulates the performance of an air-to-air direct expansion (DX) cooling system. The main difference compared to the other cooling coil models, such as Coil:DX:CoolingBypassFactorEmpirical, is that this cooling coil allows modeling of two to four discrete compressor speeds. Each speed has a set of corresponding performance information at rated conditions along with curve fits for variations in total capacity, SHR, energy input ratio and part-load fraction to determine the performance of the unit at part-load conditions (DOE 1982). The full load supply airflow rate is dependent on the speed number and provided by its parent object (Ref. UnitarySystem:MultiSpeedHeatPump:AirToAir). The part-load impact on coil energy use is automatically applied to the lowest speed. A choice is provided to determine whether part-load impacts on coil energy use are applied when the coil is operating at speeds greater than speed 1.

This model simulates the thermal performance of the indoor DX cooling coil, and the power consumption of the outdoor unit (multispeed compressor, fans, and crankcase heaters). The performance of the indoor supply air fan varies widely from system to system depending on control strategy (e.g., constant fan vs. AUTO fan), fan type, fan motor efficiency and pressure losses through the air distribution system. Therefore, this DX system model does not account for the thermal effects or electric power consumption of the indoor supply air fan. EnergyPlus contains separate models for simulating the performance of various indoor fan configurations, and these models can be easily linked with the DX system model described here to simulate the entire DX system being considered. For the time being, this coil model can only be called by the parent object Unitary System:MultiSpeedHeatPump:AirToAir.

When the model determines performance at Speed 1 (the lowest speed) or cycling between OFF and Speed 1, its performance is almost the same as the performance for the Coil:DX:CoolingBypassFactorEmpirical model. However, the outlet conditions are calculated slightly differently. Therefore, the Coil:DX:CoolingBypassFactorEmpirical model may be considered as a subset of the model described here. When the multispeed coil model determines performance at higher speeds (above 1), the model linearly interpolates the performance at two consecutive speeds (n-1 and n) as needed to meet the cooling load, with the fraction of time at each speed established by the speed ratio.

Model Inputs

The model inputs are also very similar to the inputs of the Coil:DX:CoolingBypassFactorEmpirical object. The main difference is that this multispeed model requires a set of fields at each speed, such as rated capacity, rated SHR, rated COP, two capacity modifiers, two energy input ratio modifiers, part-load correction, and latent degradation inputs. The inputs also include waste heat fraction at the rated conditions and modifier as a function of temperature to calculate recoverable waste heat for heat recovery, which are not available in the similar Coil:DX:CoolingBypassFactorEmpirical object.

Speed 1 Operation

The calculation procedures in this model are identical to the Coil:DX:CoolingBypassFactorEmpirical object (Ref: Coil:DX:CoolingBypassFactorEmpirical) with one exception: outlet node condition calculation when the supply air fan operation mode is ContFanCycComp. The following procedure provides the detailed description of the exception.

■ Total delivered cooling capacity

The total delivered cooling capacity for speed 1 operating at the cycling ratio needed to meet the requested cooling load is:

$$Q_{coil,cycling} = \dot{m}_{Speed1} * CycRatio * (h_{inlet} - h_{outlet,full})$$

where,

$Q_{coil,cyclingl}$ = delivered total cooling capacity for Speed 1 operating at a specific cycling ratio [W]

$\dot{m}_{Speed\,1}$ = air mass flow rate through cooling coil at Speed 1 as set by the parent object [kg/s]

$h_{outlet,full}$ = specific enthalpy of the coil outlet air during full-load operation at Speed 1 (no cycling) [J/kg]

h_{inlet} = specific enthalpy of the coil inlet air [J/kg]

$CycRatio$ = cycling ratio at Speed 1, ratio of requested heating load to the full-load capacity of the coil at Speed 1 [dimensionless]

It is assumed that the coil provides no cooling capacity when the coil is OFF, even if the supply air fan continues to operate.

■ Outlet air specific enthalpy

The average specific enthalpy of the coil outlet air is then calculated based on the total delivered cooling capacity and the average air mass flow rate entering the coil:

$$h_{outlet,average} = h_{inlet} - {Q_{coil,cycling}}/{\dot{m}_{inlet}}$$

where,

$h_{outlet,average}$ = averaged specific enthalpy at the coil outlet [J/kg]

h_{inlet} = specific enthalpy at the coil inlet [J/kg]

$Q_{coil,cycling}$ = total capacity at full load [W]

$\dot{m}_{inlet}$ = mass flow rate at the inlet to the coil as established by the parent object (Ref. UnitarySystem:MultiSpeedHeatPump:AirToAir, Mass Flow Rate Calculation). This flow rate is the average value determined by the parent object, accounting for the specified flow rate when the cooling coil is ON and the specified flow rate when the cooling coil is OFF for the time step being simulated.

■ Sensible capacity

The minimum humidity ratio (HR_{min}) is based on humidity ratios between inlet and full load outlet as:

HR_{min} = Minimum(HR_{inlet}, HR_{full})

where,

HR_{inlet} = Humidity ratio at the inlet [kg/kg]

HR_{full} = Full load humidity ratio at the outlet [kg/kg]

The coil sensible capacity may be calculated as:

$$Q_{coil,sens} = \dot{m}_{Speed1} * CycRatio * [h_{inlet}(T_{inlet}, HR_{\min}) - h_{outlet,full}(T_{outlet,full}, HR_{\min})]$$

where,

$Q_{coil,sens}$ = delivered sensible cooling capacity [W]

$h_{outlet,full}$ = full load specific enthalpy at the coil outlet as a function of outlet dry-bulb temperature at the full load, and the minimum humidity ratio [J/kg]

h_{inlet} = specific enthalpy at the coil inlet [J/kg]

- Latent capacity

The latent capacity is the difference between total and sensible capacities

$$Q_{coil,latent} = Q_{coil,cycling} - Q_{coil,sens}$$

where,

$Q_{coil,latent}$ = delivered latent cooling capacity [W]

- Average outlet air humidity ratio

The averaged outlet HR can be calculated as:

$$HR_{outlet,average} = HR_{inlet} - Q_{coil,latent} \Big/ \lambda \dot{m}_{inlet}$$

where,

λ = heat of vaporization as a function of HR_{min} and CycRatio*$T_{outlet,full}$+(1-CycRatio)*T_{inlet} [J/kg]

- Average outlet air temperature

Using the above averaged outlet humidity ratio and specific enthalpy, the averaged outlet temperature can be calculated using the psych function of PsyTdbFnHW.

The main reason for using the above approach is that outlet conditions are calculated in the same way in low and high speed operation.

The crankcase heater defined for this DX cooling coil is enabled during the time that the compressor is not running for either heating or cooling. The crankcase heater power use from either heating or cooling is reported in the heating coil (Coil:DX:MultiSpeed:Heating).

Higher Speed Operation

This section describes how higher speed operation is simulated. When the required sensible load is less than the full load sensible capacity at Speed n (Speed Number > 1), the following calculations are performed:

- Bypass factor at Speed n-1 and Speed n

$$BypassFactor_n = f(RatedBypassFactor_n, RatedFlowRate_n, ActualFowRate_n)$$

$$BypassFactor_{n-1} = f(RatedBypassFactor_{n-1}, RatedFlowRate_{n-1}, ActualFowRate_{n-1})$$

where,

$BypassFactor_i$ = bypass factor at actual flow rate conditions at Speed i [dimensionless]

$RatedBypassFactor_i$ = bypass factor at the rated conditions at Speed i [dimensionless]

$RatedFowRate_i$ = air mass flow rate at the rated conditions at Speed i [kg/s]

$ActualFowRate_i$ = actual air mass flow rate at Speed i [kg/s]

i = Speed n or Speed n-1

The bypass factor at Speed n is a function of the bypass factor at the rated conditions, rated airflow rate, and actual flow rate at Speed n. The calculation is performed by a function, called AdjustCBF in the DXCoil module.

- Total capacity at Speed n-1 and Speed n

$$TotCap_{n-1} = f(RatedCap_{n-1}, TotCapTempModFac_{n-1}, TotCapFlowModFac_{n-1}, BypassFactor_{n-1})$$
$$TotCap_n = f(RatedCap_n, TotCapTempModFac_n, TotCapFlowModFac_n, BypassFactor_n)$$

where,

$TotCap_i$ = total cooling capacity at given temperatures and flow rates at Speed i [w]

$RatedCap_i$ = cooling capacity at the rated conditions at Speed i [W]

$TotCapTempModFac_i$ = total cooling capacity modifier as a function of indoor web-bulb temperature and outdoor air dry-bulb temperature at Speed i

$TotCapFlowModFac_i$ = total cooling capacity modifier as a function of the ratio of the actual flow rate across the cooling coil to the rated airflow rate at Speed i

i = Speed n or Speed n-1

The calculation is performed by a subroutine, called CalcTotCapSHR in the DXCoil module.

- EIR at Speed n-1 and Speed n

$$EIR_{n-1} = RatedEIR_{n-1} * EIRTempModFac_{n-1} * EIRFlowModFac_{n-1}$$

$$EIR_n = RateEIR_n * EIRTempModFac_n * EIRFlowModFac_n$$

where,

EIR_i = Energy input ratio at given temperatures and flow rates at Speed i [w]

$RatedEIR_i$ = Energy input ratio at the rated conditions at Speed i [W]

$EIRTempModFac_i$ = Energy input ratio modifier as a function of indoor and outdoor air dry-bulb temperature at Speed i

$EIRFlowModFac_i$ = Energy input ratio modifier as a function of ratio of the actual flow rate across the heating coil to the rated airflow rate at Speed i

i = Speed n or Speed n-1

■ Full load outlet conditions at Speed n-1 and Speed n

The calculation procedure of full load outlet conditions at Speed n-1 and Speed n is the same as the calculation procedure used in the Coil:DX:CoolingBypassFactorEmpirical model (Ref. Coil:DX:CoolingBypassFactorEmpirical). The difference is that the outlet conditions at Speed n-1 are calculated based on the total cooling capacity and mass flow rate at Speed n-1, while the outlet conditions at Speed n are calculated based on the total cooling capacity and mass flow rate at Speed n.

■ Effective total cooling capacity

$$Q_{coil,SpeedRatio} = (SpeedRatio)\dot{m}_{Speed\,n}(h_{inlet} - h_{outlet,full\_Speed\,n}) + (1 - SpeedRatio)\dot{m}_{Speed\,n-1}(h_{inlet} - h_{outlet,full\_Speed\,n-1})$$

where,

$Q_{coil,SpeedRatio}$ = delivered sensible cooling capacity at a given speed ratio between two consecutive speeds [W]

$\dot{m}_{Speed\,n}$ = air mass flow rate through cooling coil at Speed n as set by the parent object [kg/s]

$\dot{m}_{Speed\,n-1}$ = air mass flow rate through cooling coil at Speed 1 as set by the parent object [kg/s]

h_{inlet} = specific enthalpy at the coil inlet [J/kg]

$h_{outlet,full\_Speed\,n}$ = full load specific enthalpy at the coil outlet at Speed n [J/kg]

$h_{outlet,full\_Speed\,n-1}$ = full load specific enthalpy at the coil outlet at Speed n-1 [J/kg]

■ Average outlet air specific enthalpy

$$h_{outlet,average} = h_{inlet} - Q_{coil,SpeedRatio} / \dot{m}_{inlet}$$

where,

$h_{outlet,average}$ = averaged specific enthalpy at the coil outlet [J/kg]

h_{inlet} = specific enthalpy at the coil inlet [J/kg]

$\dot{m}_{inlet}$ = mass flow rate at the inlet to the coil as established by the parent object (Ref. UnitarySystem:MultiSpeedHeatPump:AirToAir, Mass Flow Rate Calculation). This flow rate is the average value determined by the parent object, accounting for the specified flow rate when the heating coil is at Speed n and the specified flow rate when the heating coil is at Speed n-1 for the time step being simulated.

■ Effective sensible cooling capacity

The minimum humidity ratio (HR_{min}) is calculated as

HR_{min} = Minimum[HR_{inlet}, (SpeedRatio)$HR_{full,n}$+(1.0-SpeedRatio)$HR_{full,n-1}$)

The effective sensible cooling capacity is expressed as:

$$Q_{coil,sens} = \dot{m}_{Speed\ n}(SpeedRatio)[h_{inlet}(T_{inlet}, HR_{\min}) - h_{outlet,full\_Speed\ n}(T_{outlet,n}, HR_{\min})]$$
$$+ \dot{m}_{Speed\ n-1}(1 - SpeedRatio)[h_{inlet}(T_{inlet}, HR_{\min}) - h_{outlet,full\_Speed\ n-1}(T_{outlet,n-1}, HR_{\min})]$$

where,

$Q_{coil,sens}$ = effective sensible cooling capacity [W]

$h_{outlet,full\_Speed\ n}$ = full load specific enthalpy at the coil outlet at Speed n as a function of outlet dry-bulb temperature at the full load, and the minimum humidity ratio [J/kg]

$h_{outlet,full\_Speed\ n-1}$ = full load specific enthalpy at the coil outlet at Speed n-1 as a function of outlet dry-bulb temperature at the full load, and the minimum humidity ratio [J/kg]

h_{inlet} = specific enthalpy at the coil inlet [J/kg]

- Average outlet air humidity ratio and temperature

The effective latent cooling capacity is the difference between the total and sensible capacity:

$$Q_{coil,latent} = Q_{coil,SpeedRatio} - Q_{coil,sens}$$

$Q_{coil,latent}$ = effective latent cooling capacity [W]

The average outlet air HR can be calculated as:

$$HR_{outlet,average} = HR_{inlet} - \frac{Q_{coil,latent}}{\lambda \dot{m}_{inlet}}$$

where,

λ = heat of vaporization as a function of HR_{min} and SpeedRatio*$T_{outlet,n}$+(1-SpeedRatio)*$T_{outlet,n-1}$ [J/kg]

At the given averaged outlet humidity ratio and specific enthalpy, the averaged outlet temperature can be calculated using the psych function of PsyTdbFnHW.

- Calculate combined energy input

When the input for the field 'Apply Part Load Fraction to Speeds Greater than 1' is No in the object (equivalent to a single compressor), the combined energy output is calculated as follows:

$$CoolingPower = (TotCap_n)(EIR_n)(SpeedRatio) + (TotCap_{n-1})(EIR_{n-1})(1.0 - SpeedRatio)$$

When the input for the field 'Apply Part Load Fraction to Speeds Greater than 1' is Yes in the object (equivalent to multiple compressors), the combined energy output is calculated as follows:

$$CoolingPower = (TotCap_n)(EIR_n)(RTF) + (TotCap_{n-1})(EIR_{n-1})(1.0 - RTF)$$

where,

CoolingPower = Power used in Watt

RTF = Run time fraction at Speed n

- Latent degradation

When the supply fan operation mode is ContFanCycComp and the input of the Apply Latent Degradation to Speeds Greater than 1 is Yes, the latent degradation is included at Speed n. The calculation procedure is the same as one in the Coil:DX:CoolingBypassFactorEmpirical object. The difference is that the rated values and run time fraction at Speed n are used. The adjusted SHR is used to calculate full load outlet conditions at Speed n.

It is expected to have less latent degradation at Speed n than Speed 1. Therefore, smaller values of the latent degradation inputs at Speed n than those at Speed 1 are recommended.

- Crankcase heater

There is no power need at higher speed operation.

Waste heat calculation

The waste heat generated by this coil object is calculated as:

$$Q_{WasteHeat} = (Fraction)(TempModifier)(CoolingPowe)$$

where,

Fraction = rated waste heat fraction of the energy input

TempModifer = waste heat modifier as a function of indoor and outdoor air dry-bulb temperature

Appendix C

EnergyPlus Documentation and Reference Data Sets for Modeling Window Screens

This appendix contains the EnergyPlus documentation (Input/Output Reference and Engineering Manual sections) that describes the window screen model added as part of this project. It also contains reference data sets of model inputs for window screens which are distributed with EnergyPlus.

Input Output Reference for Material:WindowScreen

This object specifies the properties of exterior window screen materials. The window screen model assumes the screen is made up of intersecting orthogonally-crossed cylinders. The surface of the cylinders is assumed to be diffusely reflecting, having the optical properties of a Lambertian surface.

The beam solar radiation transmitted through a window screen varies with sun angle and is made up of two distinct elements: a direct beam component and a reflected beam component. The direct beam transmittance component is modeled using the geometry of the screen material and the incident angle of the sun to account for shadowing of the window by the screen material. The reflected beam component is an empirical model that accounts for the inward reflection of solar beam off the screen material surface. This component is both highly directional and small in magnitude compared to the direct beam transmittance component (except at higher incident angles, for which case the magnitude of the direct beam component is small or zero and the reflected beam component, though small in absolute terms can be many times larger than the direct beam component). For this reason, the reflected beam transmittance component calculated by the model can be a. disregarded, b. treated as an additive component to direct beam transmittance (and in the same direction), or c. treated as hemispherically-diffuse transmittance based on a user input to the model.

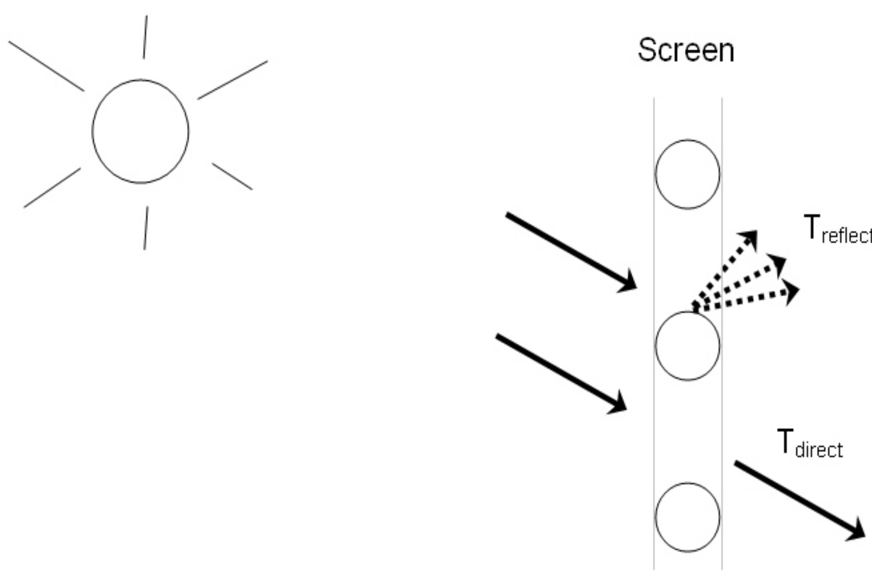


Figure 5. Direct beam and reflected beam transmittance components

The window screen “assembly” properties of overall beam solar reflectance and absorptance (including the screen material ‘cylinders’ and open area) also change with sun angle and are calculated based on the values of the beam solar transmittance components (direct and reflected components described above) and the physical properties of the screen material (i.e., screen material diameter, spacing, and reflectance).

Transmittance, reflectance, and absorptance of diffuse solar radiation are considered constant values and apply to both the front and back surfaces of the screen. These properties are calculated by the model as an average value by integrating the screen's beam solar properties over a quarter hemisphere of incident radiation. Long-wave emissivity is also assumed to be the same for both sides of the screen.

There is an EnergyPlus Reference Data Set for Material:WindowScreen that contains properties for generic window screens. Window screens of this type can only be used on the outside surface of the window ("exterior screens"). When in place, the screen is assumed to cover all of the glazed part of the window, including dividers; it does not cover any of the window frame, if present. The plane of the screen is assumed to be parallel to the glazing.

Material:WindowScreen can be used to model wire mesh insect screens where the solar and visible transmission and reflection properties vary with the angle of incidence of solar radiation. For diffusing materials such as drapery and translucent roller shades it is better to use the Material:WindowShade object. For slat-type shading devices like Venetian blinds, which have solar and visible transmission and reflection properties that strongly depend on slat angle and angle of incidence of solar radiation, it is better to use Material:WindowBlind.

There are two methods of assigning a screen to a window:

Method 1:

1) Define the construction of the window without the screen, the so-called "bare" construction.
2) Reference the bare construction in the Surface:HeatTransfer:Sub for the window.
3) Define the Material:WindowScreen object.
4) Define a WindowShadingControl for the window in which you (a) specify that this Material:WindowScreen is the window's shading device, and (b) specify how the screen is controlled.

Method 2:

1. Define the Construction of the window without the screen, the so-called "bare" construction.
2. Reference the bare construction in the Surface:HeatTransfer:Sub for the window.
3. Define the Material:WindowScreen object.
4. Define another Construction, called the "shaded construction," that includes the Material:WindowScreen.
5. Define a WindowShadingControl for the window in which you (a) reference the shaded construction, and (b) specify how the screen is controlled.

Note that WindowShadingControl has to be used with either method, even if the screen is in place at all times. You will get an error message if you try to reference a shaded construction directly from a Surface:HeatTransfer:Sub object.

Field: Name

Enter a unique name for the screen. This name is referenced as an outside layer in a window construction.

Field: Reflected Beam Transmittance Accounting Method

This input specifies the method used to account for screen-reflected beam solar radiation that is transmitted through the window screen (as opposed to being reflected back outside the building). Since this inward reflecting beam solar is highly directional and is not modeled in the direction of the actual reflection, the user is given the option of how to account for the directionality of this component of beam solar transmittance. Valid choices are Do Not Model, Model as Direct Beam (i.e., model as an additive component to direct solar beam and in the same direction), or Model as Diffuse (i.e., model as hemispherically-diffuse radiation). The default value is Model as Diffuse.

Field: Diffuse Solar Reflectance

This input specifies the solar reflectance (beam-to-diffuse) of the screen material itself (not the effective value for the overall screen "assembly" including open spaces between the screen material). The outgoing diffuse radiation is assumed to be Lambertian (distributed angularly according to Lambert's cosine law). The solar reflectance is assumed to be the same for both sides of the screen. This value must be from 0 to less than 1.0. In the absence of better information, the input value for diffuse solar reflectance should match the input value for diffuse visible reflectance.

Field: Diffuse Visible Reflectance

This input specifies the visible reflectance (beam-to-diffuse) of the screen material itself (not the effective value for the overall screen "assembly" including open spaces between the screen material) averaged over the solar spectrum and weighted by the response of the human eye. The outgoing diffuse radiation is assumed to be Lambertian (distributed angularly according to Lambert's cosine law). The visible reflectance is assumed to be the same for both sides of the screen. This value must be from 0 to less than 1.0.

If diffuse visible reflectance for the screen material is not available, then the following guidelines can be used to estimate this value:

Dark-colored screen (e.g., charcoal):	0.08 – 0.10
Medium-colored screen (e.g., gray):	0.20 – 0.25
Light-colored screen (e.g., bright aluminum):	0.60 – 0.65

Commercially-available gray scale or grayscale reflecting chart references can be purchased for improved accuracy in estimating visible reflectance (by visual comparison of screen reflected brightness with that of various known-reflectance portions of the grayscale).

Field: Thermal Hemispherical Emissivity

Long-wave emissivity ε of the screen material itself (not the effective value for the overall screen "assembly" including open spaces between the screen material). The emissivity is assumed to be the same for both sides of the screen.

For most non-metallic materials, ε is about 0.9. For metallic materials, ε is dependent on material, its surface condition, and temperature. Typical values for metallic materials range from 0.05 – 0.1 with lower values representing a more finished surface (e.g. low oxidation, polished surface). Material emissivities may be found in Table 5 from the 2005 ASHRAE Handbook of Fundamentals, page 3.9. The value for this input field must be between 0 and 1, with a default value of 0.9 if this field is left blank.

Field: Conductivity

Screen material conductivity (W/m-K). This input value must be greater than 0. The default value is 221 W/m-K (aluminum).

Field: Screen Material Spacing

The spacing, S, of the screen material (m) is the distance from the center of one strand of screen to the center of the adjacent one. The spacing of the screen material is assumed to be the same in both directions (e.g., vertical and horizontal). This input value must be greater than the non-zero screen material diameter. If the spacing is different in the two directions, use the average of the two values.

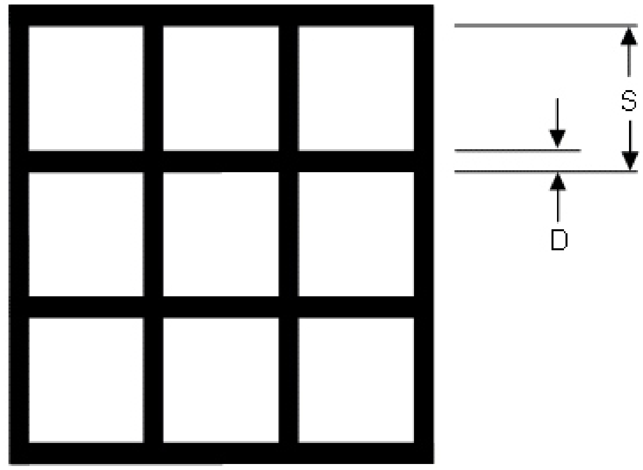


Figure 6. Screen Material Spacing and Diameter

Field: Screen Material Diameter

The diameter, D, of individual strands or wires of the screen material (m). The screen material diameter is assumed to be the same in both directions (e.g., vertical and horizontal). This input value must be greater than 0 and less than the screen material spacing. If the diameter is different in the two directions, use the average of the two values.

Field: Screen-to-Glass Distance

Distance from the window screen to the adjacent glass surface (m). If the screen is not flat, the average screen-to-glass distance should be used. The screen-to-glass distance is used in calculating the natural convective air flow between the glass and the screen produced by buoyancy effects. This input value must be from 0.001 m to 1 m, with a default value of 0.025 m if this field is left blank.

Field: Top Opening Multiplier

Effective area for air flow at the top of the screen divided by the horizontal area between the glass and screen (see the same field for the Material:WindowShade object for additional description). The opening multiplier fields can be used to simulate a shading material that is offset from the window frame. Since window screens are typically installed against the window frame, the default value is equal to 0.This input value can range from 0 to 1.

Field: Bottom Opening Multiplier

Effective area for air flow at the bottom of the screen divided the horizontal area between the glass and screen (see the same field for the Material:WindowShade object for additional description). The opening multiplier fields can be used to simulate a shading material that is offset from the window frame. Since window screens are typically installed against the window frame, the default value is equal to 0. This input value can range from 0 to 1.

Field: Left-Side Opening Multiplier

Effective area for air flow at the left side of the screen divided the vertical area between the glass and screen (see the same field for the Material:WindowShade object for additional description). The opening multiplier fields can be used to simulate a shading material that is offset from the window frame. Since window screens are typically installed against the window frame, the default value is equal to 0. This input value can range from 0 to 1.

Field: Right-Side Opening Multiplier

Effective area for air flow at the right side of the screen divided the vertical area between the glass and screen (see the same field for the Material:WindowShade object for additional description). The opening multiplier fields can be used to simulate a shading material that is offset from the window frame. Since window screens are typically installed against the window frame, the default value is equal to 0. This input value can range from 0 to 1.

Field: Angle of Resolution for Screen Transmittance Output Map

Angle of resolution, in degrees, for the overall screen beam transmittance (direct and reflected) output map. The comma-separated variable file eplusscreen.csv (Ref. OutputDetailsandExamples.pdf) will contain the direct beam and reflected beam solar radiation that is transmitted through the window screen as a function of incident sun angle (0 to 90 degrees relative solar azimuth and 0 to 90 degrees relative solar altitude) in sun angle increments specified by this input field. The default value is 0, which means no transmittance map is generated. Other valid choice inputs are 1, 2, 3 and 5 degrees.

The input data dictionary (IDD) definition for this object is shown below:

```
MATERIAL:WINDOWSCREEN,
       \memo Window screen physical properties. Can only be located on the exterior side of a
             window construction.
       \min-fields 9
  A1 , \field Name
       \note Enter a unique name for this window screen material.
       \required-field
       \type alpha
       \reference MaterialName
       \reference WindowShadesScreensAndBlinds
  A2 , \field Reflected Beam Transmittance Accounting Method
       \note Select the method used to account for the beam solar reflected off the material
             surface.
       \type choice
       \key Do Not Model
       \key Model As Direct Beam
       \key Model As Diffuse
       \default Model As Diffuse  N1 , \field Diffuse Solar Reflectance
       \note Diffuse reflectance of the screen material over the entire solar radiation spectrum.
       \note Assumed to be the same for both sides of the screen.
       \required-field
       \type real
       \units dimensionless
       \minimum 0
       \maximum< 1
  N2 , \field Diffuse Visible Reflectance
       \note Diffuse visible reflectance of the screen material averaged over the solar spectrum
       \note and weighted by the response of the human eye.
       \note Assumed to be the same for both sides of the screen.
       \required-field
       \type real
       \units dimensionless
       \minimum 0
       \maximum< 1
  N3 , \field Thermal Hemispherical Emissivity
       \note Long-wave emissivity of the screen material.
       \note Assumed to be the same for both sides of the screen.
       \type real
       \units dimensionless
       \maximum< 1
       \minimum> 0
       \default 0.9
  N4 , \field Conductivity
       \note Thermal conductivity of the screen material.
       \type real
       \units W/m-K
       \minimum> 0
       \default 221.0
       \note Default is for aluminum.
  N5 , \field Screen Material Spacing
       \note Spacing assumed to be the same in both directions.
       \required-field
       \type real
       \units m
       \minimum> 0
       \ip-units in
  N6 , \field Screen Material Diameter
       \note Diameter assumed to be the same in both directions.
       \required-field
       \type real
       \units m
       \minimum> 0
       \ip-units in
  N7 , \field Screen-to-Glass Distance
       \note Distance from the window screen to the adjacent glass surface.
       \type real
       \units m
       \minimum 0.001
       \maximum 1.0
       \default 0.025
       \ip-units in
```

```
N8 , \field Top Opening Multiplier
     \note Effective area for air flow at the top of the screen divided by the perpendicular
     \note area between the glass and the top of the screen.
     \type real
     \units dimensionless
     \minimum 0.0
     \maximum 1.0
     \default 0.0
N9 , \field Bottom Opening Multiplier
     \note Effective area for air flow at the bottom of the screen divided by the perpendicular
     \note area between the glass and the bottom of the screen.
     \type real
     \units dimensionless
     \minimum 0.0
     \maximum 1.0
     \default 0.0
N10, \field Left-Side Opening Multiplier
     \note Effective area for air flow at the left side of the screen divided by the
           perpendicular
     \note area between the glass and the left side of the screen.
     \type real
     \units dimensionless
     \minimum 0.0
     \maximum 1.0
     \default 0.0
N11, \field Right-Side Opening Multiplier
     \note Effective area for air flow at the right side of the screen divided by the
           perpendicular
     \note area between the glass and the right side of the screen.
     \type real
     \units dimensionless
     \minimum 0.0
     \maximum 1.0
     \default 0.0
N12; \field Angle of Resolution for Screen Transmittance Output Map
     \note Select the resolution of azimuth and altitude angles for the screen transmittance
           map.
     \note A value of 0 means no transmittance map will be generated.
     \note Valid values for this field are 0, 1, 2, 3 and 5.
     \type choice
     \units deg
     \key 0
     \key 1
     \key 2
     \key 3
     \key 5
     \default 0
```

An IDF example for this object, along with CONSTRUCTION and WindowShadingControl objects, is shown below:

```
MATERIAL:WindowScreen,
  EXTERIOR SCREEN,         !- Name
  Model As Diffuse,        !- Reflected Beam Transmittance Accounting Method
  0.6,                     !- Diffuse Solar Reflectance
  0.6,                     !- Diffuse Visible Reflectance
  0.9,                     !- Thermal Hemispherical Emissivity
  221.0,                   !- Conductivity {W/m-K}
  0.00154,                 !- Screen Material Spacing (m)
  0.000254,                !- Screen Material Diameter (m)
  0.025,                   !- Screen-to-Glass Distance {m}
  0.0,                     !- Top Opening Multiplier
  0.0,                     !- Bottom Opening Multiplier
  0.0,                     !- Left-Side Opening Multiplier
  0.0,                     !- Right-Side Opening Multiplier
  0;                       !- Angle of Resolution for Screen Transmittance Output Map {deg}

CONSTRUCTION,
  DOUBLE PANE WITHOUT SCREEN,     !- Name
  GLASS - CLEAR SHEET 1 / 8 IN,   !- Outside Layer
  WinAirB1 - AIRSPACE RESISTANCE, !- Layer #2
  GLASS - CLEAR SHEET 1 / 8 IN;   !- Layer #3

WINDOWSHADINGCONTROL,
  DOUBLE PANE WITH SCREEN, !- User Supplied Shading Control Name
  ExteriorScreen,          !- Shading Type
  ,                        !- Name of construction with shading
  AlwaysOn,                !- Shading Control Type
  ScreenSchedule,          !- Schedule Name
  20.0,                    !- SetPoint {W/m2, W or deg C}
  YES,                     !- Shading Control Is Scheduled
  NO,                      !- Glare Control Is Active
  EXTERIOR SCREEN,         !- Material Name of Shading Device
  ,                        !- Type of Slat Angle Control for Blinds
  ;                        !- Slat Angle Schedule Name
```

Engineering Document for Material:WindowScreen

Window Calculation Module

Optical Properties of Window Shading Devices

Shading devices affect the system transmittance and glass layer absorptance for short-wave radiation and for long-wave (thermal) radiation. The effect depends on the shade position (interior, exterior or between-glass), its transmittance, and the amount of inter-reflection between the shading device and the glazing. Also of interest is the amount of radiation absorbed by the shading device.

In EnergyPlus, shading devices are divided into four categories, “shades,” ”blinds,” “screens,” and “switchable glazing.” “Shades” are assumed to be perfect diffusers. This means that direct radiation incident on the shade is reflected and transmitted as hemispherically uniform diffuse radiation: there is no direct component of transmitted radiation. It is also assumed that the transmittance, τ_{sh}, reflectance, ρ_{sh}, and absorptance, α_{sh}, are the same for the front and back of the shade and are independent of angle of incidence. Many types of drapery and pull-down roller devices are close to being perfect diffusers and can be categorized as “shades.”

“Blinds” in EnergyPlus are slat-type devices such as venetian blinds. Unlike shades, the optical properties of blinds are strongly dependent on angle of incidence. Also, depending on slat angle and the profile angle of incident direct radiation, some of the direct radiation may pass between the slats, giving a direct component of transmitted radiation.

“Screens” are debris or insect protection devices made up of metallic or non-metallic materials. Screens may also be used as shading devices for large glazing areas where excessive solar gain is an issue. The EnergyPlus window screen model assumes the screen is composed of intersecting orthogonally-crossed cylinders, with the surface of the cylinders assumed to be diffusely reflecting. Screens may only be used on the exterior surface of a window construction. As with blinds, the optical properties affecting the direct component of transmitted radiation are dependent on the angle of incident direct radiation.

With “Switchable glazing,” shading is achieved making the glazing more absorbing or more reflecting, usually by an electrical or chemical mechanism. An example is electrochromic glazing where the application of an electrical voltage or current causes the glazing to switch from light to dark.

Shades and blinds can be either fixed or moveable. If moveable, they can be deployed according to a schedule or according to a trigger variable, such as solar radiation incident on the window. Screens can be either fixed or moveable according to a schedule.

Screens

The model for window screens currently allows placement on the exterior surface of a window system (i.e., between glass and interior window screens can not be modeled). The exterior screen is modeled as a planar semi-transparent sheet having specular transmittance that is dependent on the angle of incidence of beam solar radiation. The screen transmittance algorithm includes two components. The first one, T_{beam} (α’, φ'), accounts for the blockage of the sun’s rays by the screen material. This component accounts for the beam solar radiation passing through the screen openings without hitting the screen material. The second part, T_{scatt} (α’, φ'), accounts for the additional flux of transmitted beam solar radiation by diffuse reflectance (scattering) from the screen material. Since the reflected component is small compared with the incident beam and the direction of scattering is highly dependent on incident angle, the component of transmitted beam radiation due to screen material reflectance can be treated in one of three ways based on a user input to the model.

The user may elect not to model the inward reflected beam transmittance due to the uncertainty of the direction of scattering or its low magnitude for low-reflecting screen materials. The user may alternately choose to model the inwardly-reflected transmitted beam as an additive component to the direct beam transmittance in the same solid angle and direction. Finally, the additional flux due to the inward reflection of direct beam radiation may be modeled as hemispherically-diffuse transmittance.

This reflected beam transmittance component depends upon the diffuse (i.e., beam-to-diffuse) reflectance of the screen material, so this reflectance (ρ_{sc}) is a required input to the model. Guidance input values for this diffuse reflectance are provided, to account for screens that are dark, medium, or light colored in appearance, in the likely case that more accurate values for the material reflectance are difficult or time-consuming to obtain. If the diffuse reflectance of the screen material is known, use this value in place of the guidance provided.

The model is based on an orthogonal crossed cylinder geometry in which the screen material’s cylindrical diameter and spacing are known. The model assumes that the screen material diameter and spacing are the same in both directions. Figure 7 shows a rendering of intersecting orthogonal crossed cylinders used as the basis for the EnergyPlus screen model.

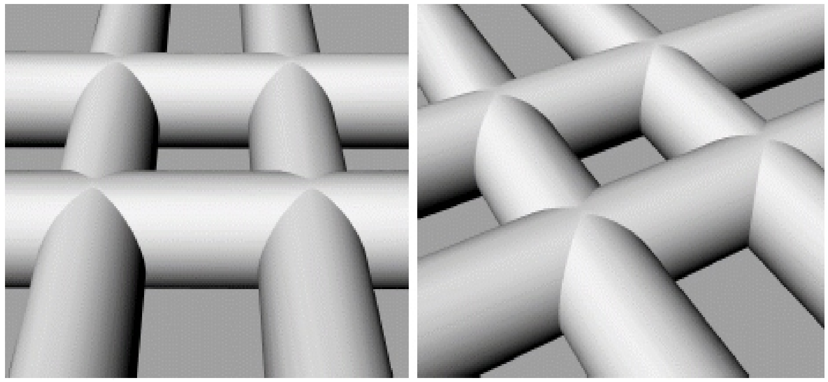


Figure 7. Screen model rendering of intersecting orthogonal crossed cylinders

If the required screen material dimensions are not available from the manufacturer, they may be determined using the following procedure:

- Lay the screen next to a finely-divided scale or ruler. A magnifying glass may be helpful in determining the screen material dimensions. Alternately, a photograph can be taken and the image enlarged.
- Determine the diameter *D* of an individual screen material "cylinder". Average the diameter values if different in opposing directions.
- Determine the average center-to-center spacing *S* of the screen material or measure from one side of a "cylinder" to the same side of the next "cylinder" and record the spacing *S*. Average the spacing values if different in opposing directions.
- Enter these values as inputs to the exterior window screen model.

The screen material diameter and spacing are then used to determine the screen material aspect ratio for use in the screen model.

$$\gamma = D/S$$

where

γ = Screen material aspect ratio, dimensionless

D = Screen material diameter, m

S = Screen material spacing, m

Figure 8 below shows the input requirements for material diameter and spacing and the associated calculation for openness factor, the equivalent to T_{beam} at direct normal incidence.

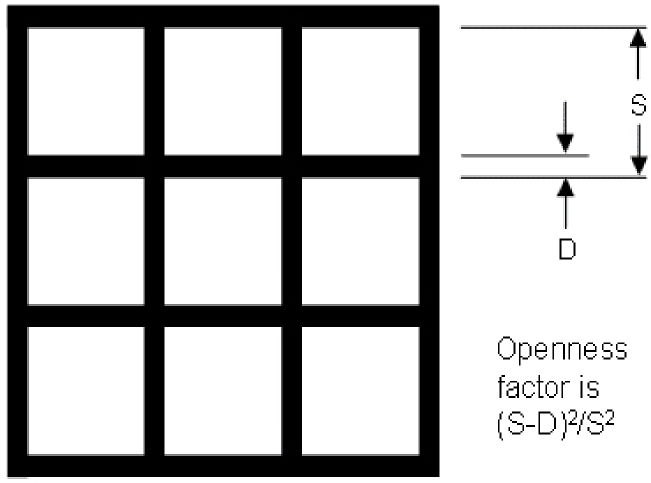


Figure 8. Physical screen material properties

Screen Beam Transmittance

The first component of the window screen transmittance model is a geometric representation of the open area of the screen material and is dependent on the angle of incident beam radiation. Figure 9 shows a schematic of a South-facing vertical window screen and the solar angles used in EnergyPlus. The window screen model is based on the relative angles of incidence of the sun's rays with respect the the window screen outward normal. In the figure, the relative solar azimuth and relative solar altitude are represented as φ' and α', respectively.

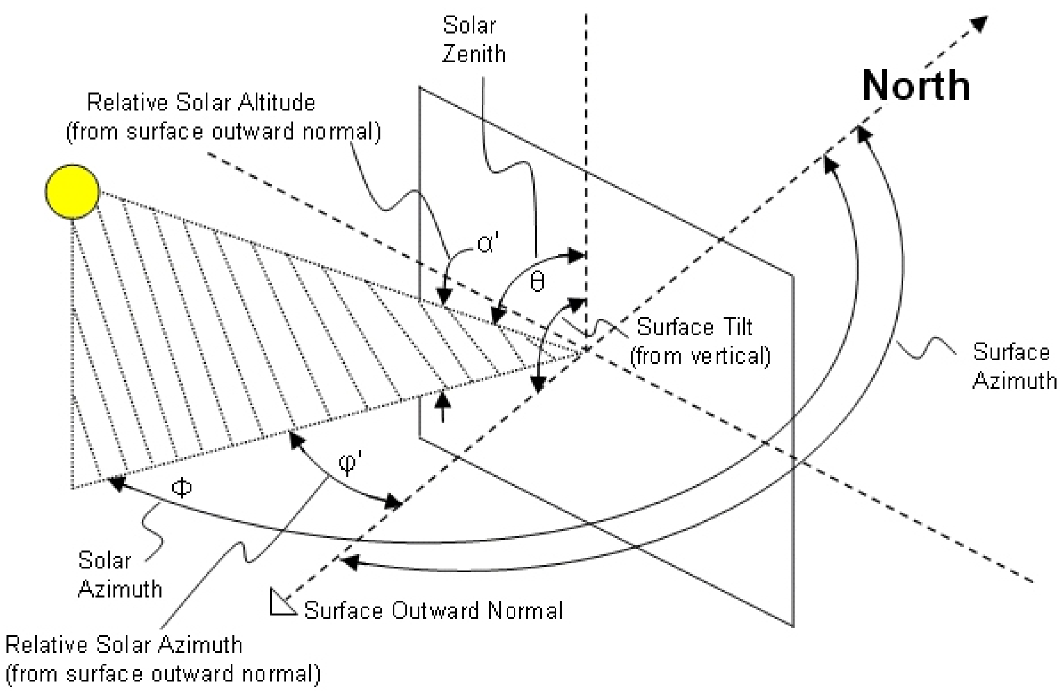


Figure 9. Schematic of a vertical window screen facing due South

Given the diffuse reflectance ρ_{sc} and the screen aspect ratio γ, the model takes the direction of solar incidence, the relative solar altitude angle α' and the relative solar azimuth angle φ', illustrated in Figure 9, and calculates the direct beam transmittance

T_{beam} (α', φ') as follows. Since the direct beam transmittance is only a function of the incident angle and the screen material aspect ratio, the following applies to both solar and visible radiation.

$$\alpha'' = \arctan\left(\tan\alpha'\sec\varphi'\right)$$

$$\beta = \frac{\pi}{2} - \varphi'$$

$$T_y = 1 - \gamma\left[\cos\alpha'' + \sin\alpha''\tan\alpha'\left(1+\cot^2\beta\right)^{\frac{1}{2}}\right]$$

$$\mu = \arccos\left(\left[\cos^2\alpha'\cos^2\varphi' + \sin^2\alpha'\right]^{\frac{1}{2}}\right)$$

$$\varepsilon = \arccos\left(\left[\cos\alpha'\cos\varphi'\right] \big/ \cos\mu\right)$$

$$\eta = \frac{\pi}{2} - \varepsilon$$

$$\mu' = \arctan\left(\tan\mu\sec\varepsilon\right)$$

$$T_x = 1 - \gamma\left[\cos\mu' + \sin\mu'\tan\mu\left(1+\cot^2\eta\right)^{\frac{1}{2}}\right]$$

$$T_{beam}\left(\alpha',\varphi'\right) = T_{beam}^{vis}\left(\alpha',\varphi'\right) = T_x T_y$$

where

T_y = vertical component of direct beam transmittance

T_x = horizontal component of direct beam transmittance

T_{beam} = direct screen transmittance that accounts for beam solar radiation passing through the screen openings without hitting the screen material

T_{beam}^{vis} = direct visible screen transmittance that accounts for beam solar radiation passing through the screen openings without hitting the screen material

α' = relative solar altitude angle [radians]

φ' = relative solar azimuth angle [radians]

γ = Screen material aspect ratio, dimensionless

$\alpha'', \beta, \mu, \varepsilon, \eta, \mu'$ = intermediate variables

This first component of screen direct beam transmittance was developed using geometric principals and was verified using an optical ray tracing software program.

The second component of the window screen transmittance model is an empirical algorithm that accounts for the inward reflection of incident beam radiation off the screen material surface. The calculation procedure for the screen's transmittance via beam reflection, T_{scatt} (α', φ') is as follows:

$$T_{scattmax} = 0.0229\,\gamma + 0.2971\,\rho_{sc} - 0.03624\,\gamma^2 + 0.04763\,\rho_{sc}{}^2 - 0.44416\,\gamma\,\rho_{sc}$$

$$T^{vis}_{scattmax} = 0.0229\,\gamma + 0.2971\,\rho^{vis}_{sc} - 0.03624\,\gamma^2 + 0.04763\left(\rho^{vis}_{sc}\right)^2 - 0.44416\,\gamma\,\rho^{vis}_{sc}$$

$$\delta_{max} = 89.7 - 10\gamma/0.16$$

$$\delta = \left(\alpha'^2_d + \varphi'^2_d\right)^{\frac{1}{2}}$$

$$Peak_{ratio} = 1.0 \Big/ \left(0.2\rho_{sc}\left(1-\gamma\right)\right)$$

$$Peak^{vis}_{ratio} = 1.0 \Big/ \left(0.2\rho^{vis}_{sc}\left(1-\gamma\right)\right)$$

$$T_{scatt}\left(\alpha',\varphi'\right) = 0.2\rho_{sc}T_{scattmax}\left(1-\gamma\right)\left(1+\left(Peak_{ratio}-1\right)e^{\frac{-\left|\delta-\delta_{max}\right|^{2.0}}{600}}\right)$$

$$T^{vis}_{scatt}\left(\alpha',\varphi'\right) = 0.2\rho^{vis}_{sc}T^{vis}_{scattmax}\left(1-\gamma\right)\left(1+\left(Peak^{vis}_{ratio}-1\right)e^{\frac{-\left|\delta-\delta_{max}\right|^{2.0}}{600}}\right)$$

$$IF\left(\delta > \delta_{max}\right)\, T_{scatt}\left(\alpha',\varphi'\right) = 0.2\rho_{sc}T_{scattmax}\left(1-\gamma\right)\left(1+\left(Peak_{ratio}-1\right)e^{\frac{-\left|\delta-\delta_{max}\right|^{2.5}}{600}}\right) - 0.2\rho_{sc}T_{scattmax}\left(1-\gamma\right)\left(MAX\left(0.0,\frac{\delta-\delta_{\max}}{90.-\delta_{\max}}\right)\right)$$

$$IF\left(\delta > \delta_{max}\right)\, T^{vis}_{scatt}\left(\alpha',\varphi'\right) = 0.2\rho^{vis}_{sc}T^{vis}_{scattmax}\left(1-\gamma\right)\left(1+\left(Peak^{vis}_{ratio}-1\right)e^{\frac{-\left|\delta-\delta_{max}\right|^{2.5}}{600}}\right) - 0.2\rho^{vis}_{sc}T^{vis}_{scattmax}\left(1-\gamma\right)\left(MAX\left(0.0,\frac{\delta-\delta_{\max}}{90.-\delta_{\max}}\right)\right)$$

where

$T_{scattmax}$ = maximum reflected (scattered) beam transmittance

$T^{vis}_{scattmax}$ = maximum visible reflected (scattered) beam transmittance

δ_{max}, δ = intermediate variables [degrees]

$\alpha^{'}_{d}$ = relative solar altitude [degrees]

$\varphi^{'}_{d}$ = relative solar azimuth [degrees]

$Peak_{ratio}$ = Ratio of peak scattered beam transmittance to scattered beam transmittance at direct normal incidence.

$Peak^{vis}_{ratio}$ = Ratio of peak scattered visible transmittance to scattered visible transmittance at direct normal incidence.

ρ_{sc} = diffuse solar reflectance of the screen material

ρ^{vis}_{sc} = diffuse visible reflectance of the screen material

T_{scatt} = beam solar transmittance due to reflectance (scattering)

T^{vis}_{scatt} = beam visible transmittance due to reflectance (scattering)

The reflected (scattered) transmittance of incident beam radiation is an empirical model derived by curvefitting results from optical ray trace modeling. Ray traces were performed for a range of screen aspect ratios, diffuse screen reflectances, and relative solar azimuth and altitude angles. The surface of the screen cylinders was assumed to be diffusely reflecting, having the optical properties of a Lambertian surface. The transmitted flux due to reflection was determined by a hemispherical detector on the transmitted side of the screen.

These two components of beam solar transmittance are then used to specify the properties for beam-to-beam and beam-to-diffuse transmittance for the screen based on the user selection for Reflected Beam Transmittance Accounting Method in the Material: WindowScreen object. The calculations below apply to both the solar and visible beam solar transmittance.

If the user selects Do Not Model, the direct beam transmittance is set to T_{beam} and the reflected (scattered) portion of the beam solar transmittance is ignored:

$$T^{dir,dir}_{sc} = T_{beam}\left(\alpha', \varphi'\right)$$

$$T^{dir,dif}_{sc} = 0.0$$

$$T^{dir,dir}_{sc,vis} = T_{beam}\left(\alpha', \varphi'\right)$$

$$T_{sc,vis}^{dir,dif} = 0.0$$

where

$T_{sc}^{dir,dir}$ = direct-to-direct beam transmittance of the screen (output report variable Screen Beam-Beam Solar Transmittance)

$T_{sc}^{dir,dif}$ = direct-to-diffuse beam transmittance of the screen (output report variable Screen Beam-Diffuse Solar Transmittance)

$T_{sc,vis}^{dir,dir}$ = direct-to-direct visible transmittance of the screen

$T_{sc,vis}^{dir,dif}$ = direct-to-diffuse visible transmittance of the screen

If the user selects Model as Direct Beam, the reflected (scattered) portion of the beam solar transmittance is added to the direct beam transmittance T_{beam} in the same solid angle and direction of the unattenuated solar beam:

$$T_{sc}^{dir,dir} = T_{beam}\left(\alpha',\varphi'\right) + T_{scatt}\left(\alpha',\varphi'\right)$$

$$T_{sc}^{dir,dif} = 0.0$$

$$T_{sc,vis}^{dir,dir} = T_{beam}\left(\alpha',\varphi'\right) + T_{scatt}^{vis}\left(\alpha',\varphi'\right)$$

$$T_{sc,vis}^{dir,dif} = 0.0$$

If the user selects Model as Diffuse Beam, the direct beam transmittance is set to T_{beam} and the reflected (scattered) portion of the beam solar transmittance is modeled as diffuse hemispherical radiation:

$$T_{sc}^{dir,dir} = T_{beam}\left(\alpha',\varphi'\right)$$

$$T_{sc}^{dir,dif} = T_{scatt}\left(\alpha',\varphi'\right)$$

$$T_{sc,vis}^{dir,dir} = T_{beam}\left(\alpha',\varphi'\right)$$

$$T_{sc,vis}^{dir,dif} = T_{scatt}^{vis}\left(\alpha',\varphi'\right)$$

Screen Beam Reflectance

The screen reflectance (overall value for the screen assembly, accounting for the screen material itself and the open spaces between the screen material) is calculated by first subtracting the direct-to-direct screen transmittance from the unit incident beam. This approximates the fraction of incident beam solar radiation striking the screen that is not inwardly transmitted. The result is then multiplied by the screen material diffuse reflectance ρ_{sc}. The inwardly scattered transmittance is then subtracted from this quantity to obtain an approximate value for the screen's reflectance R_{sc} to beam radiation incident as a function of the relative angles of incident radiation. This equation is used for both beam and visible reflectance:

$$R_{SC}^{dir,dif}\left(\alpha',\varphi'\right)=\rho_{SC}\left(1-T_{SC}^{dir,dir}\right)-T_{SC}^{dir,dif}$$

$$R_{SC,vis}^{dir,dif}\left(\alpha',\varphi'\right)=\rho_{SC}^{vis}\left(1-T_{SC,vis}^{dir,dir}\right)-T_{SC,vis}^{dir,dif}$$

Screen Beam Absorptance

The screen absorptance (overall value for the screen assembly, accounting for the screen material itself and the open spaces between the screen material) is calculated as the quantity of the unit incident flux (1) less the directly-transmitted component $T_{dir,dir}$ multiplied by the quantity 1 minus the screen material diffuse reflectance.

$$A_{SC}^{dir}\left(\alpha',\varphi'\right)=\left(1-T_{SC}^{dir,dir}\right)\left(1-\rho_{SC}\right)$$

Screen Diffuse Properties

The transmittance of the screen to half-hemispherical diffuse (sky) radiation is calculated by performing a finite-element-summation, approximately equivalent to an integration over the solid angle of the beam transmittance, assuming uniform radiance. This single-number screen diffuse transmittance is then multiplied by the irradiance incident on the screen from a uniform half-hemisphere of sky- or ground-reflected radiation to determine the level of additional flux transmitted by the screen to the window from the diffuse sky or ground. The sun angles shown in the figure below represent the solar altitude angle (θ) and solar azimuth angle (Φ) in polar coordinates. These angles are used to calculate the average diffuse-to-diffuse properties for screens in the following derivations.

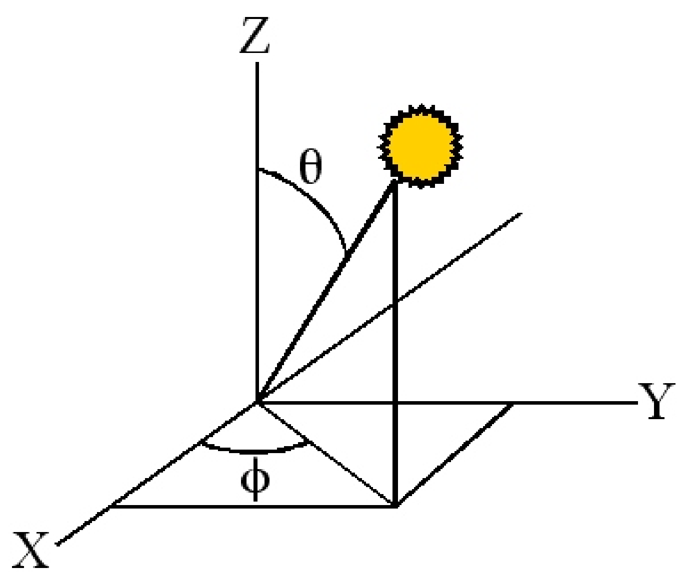


Figure 10. Sun Angles in Screen Calculations.

The screen transmittance to diffuse radiation $T_{dif,dif}$ (γ, ρ_{sc}) is computed as the integrated average of the combined beam transmittance T_{tot} (γ, ρ, θ, Φ) over the directions of incidence using spherical coordinates (θ, Φ) in which the z-axis is perpendicular to the plane of the screen. Using a finite element computation, this is:

$$T_{tot}(\gamma,\rho_{sc},\theta_j,\phi_i) = T_{beam}\left(\alpha',\varphi'\right) + T_{scatt}\left(\alpha',\varphi'\right)$$

$$T_{sc}^{dif,dif}(\gamma,\rho_{sc}) = \frac{\sum_{j=1}^{N}\sum_{i=1}^{M} T_{tot}(\gamma,\rho_{sc},\theta_j,\phi_i)\ \sin(\theta_j)\ \cos(\theta_j)}{\sum_{j=1}^{N}\sum_{i=1}^{M} \sin(\theta_j)\ \cos(\theta_j)}$$

where

θ = solar altitude angle in polar coordinates [radians]

ϕ = solar azimuth angle in polar coordinates [radians]

$T_{sc}^{dif,dif}(\gamma,\rho_{sc})$ = diffuse-diffuse transmittance (output report variable Screen Diffuse-Diffuse Solar Transmittance)

Similarly, the reflectance of the screen to diffuse radiation is given by

$$R_{sc}^{dif,dif}(\gamma,\rho_{sc}) = \frac{\sum_{j=1}^{N}\sum_{i=1}^{M} R_{sc}^{dir,dif}(\gamma,\rho_{sc},\theta_j,\phi_i)\ \sin(\theta_j)\ \cos(\theta_j)}{\sum_{j=1}^{N}\sum_{i=1}^{M} \sin(\theta_j)\ \cos(\theta_j)}$$

There is an assumption in both of these formulas that the brightness of the sky (or ground) diffuse radiation is the same for all directions. For this reason, the solar azimuth angle Φ and solar altitude angle θ have a range of 0 to $\pi/2$ (instead of $-\pi/2$ to $+\pi/2$) because the screen is assumed to have identical optical properties for radiation incident at the same angles on either side of a vertical or horizontal plane perpendicular to the screen.

Since the screen direct transmittance model is derived with respect to a different coordinate axis labeling, a coordinate transform is needed in order to calculate the diffuse optical properties. In these calculations, for each spherical solar coordinates (θ, Φ) we need the corresponding screen relative solar coordinates (α', φ') to evaluate the screen transmittance model for that direction.

For each θ and Φ in the summation, the corresponding values for the relative solar altitude α' and relative solar azimuth φ' needed to calculate screen transmittance are determined with the following coordinate transform equations:

$$\sin\alpha' = \sin\theta\cos\phi$$

$$\tan\varphi' = \tan\theta\sin\phi$$

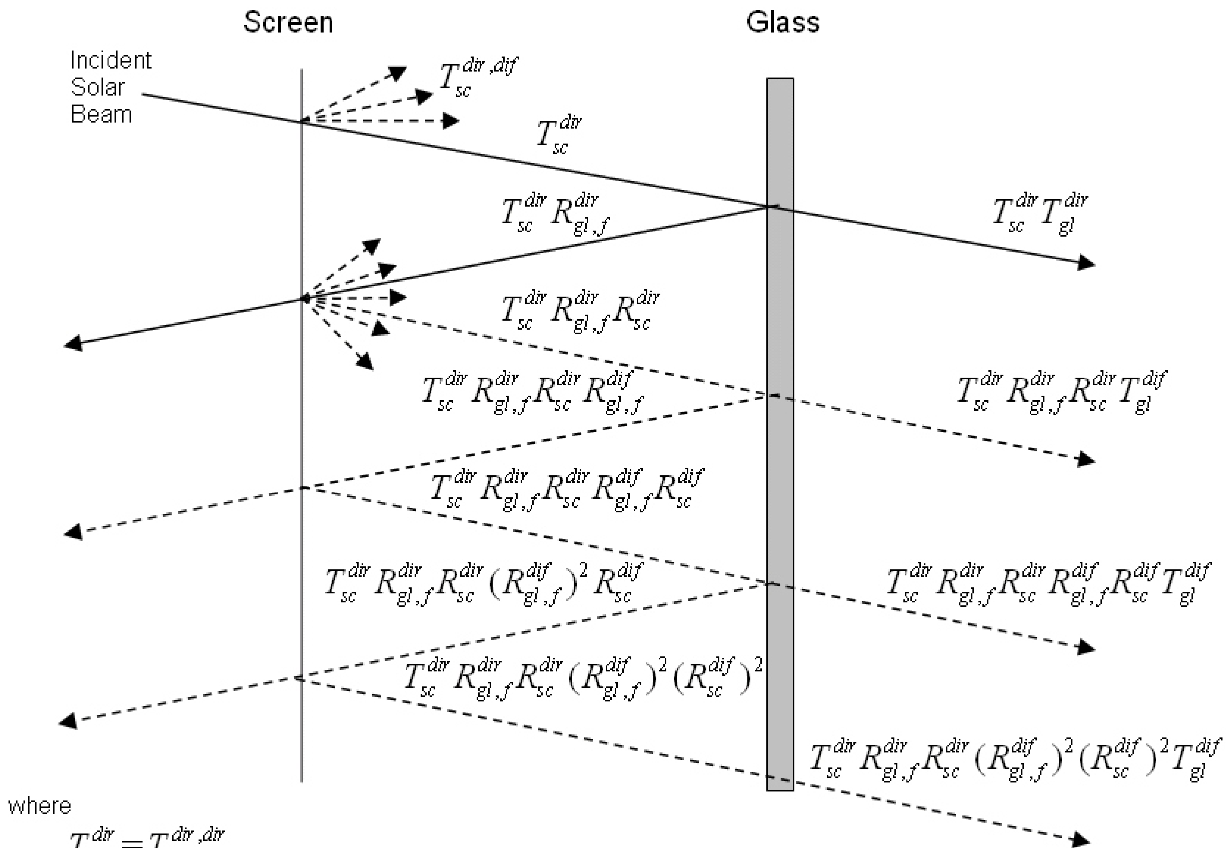
The absorptance of the screen to diffuse incident radiation is calculated by subtracting the diffuse transmittance and diffuse reflectance from unity as follows:

$$A_{sc}^{dif}(\gamma,\rho_{sc}) = 1 - T_{sc}^{dif,dif}(\gamma,\rho_{sc}) - R_{sc}^{dif,dif}(\gamma,\rho_{sc})$$

Screen/Glass System Properties for Short-Wave Radiation

The combined system properties of the screen/glass combination are calculated using the properties of the screen in combination with the bare glass material properties. Interreflections of radiation between the screen and glass surfaces are included. The following infinite series serves as an example for calculating the combined screen/glass system properties. The terms of the series are built up as illustrated in the following figure. The terms shown at the right of the figure represent each term in the infinite series for the combined screen/glass property (beam transmittance in this example).

For the example of beam transmittance, the incident solar beam strikes the screen at the incident angle associated with the current relative azimuth and altitude angle. The incident beam splits into reflected and transmitted components at the screen. The transmitted component is attenuated as it passes through the screen material by the screen's beam transmittance ($T_{sc}^{dir,dir}$, shown as T_{sc}^{dir} in the figure and equations below) at this incident angle. The reflected (scattered) transmittance of incident solar beam is also shown at this point and will be discussed later in this section. As the attenuated solar beam continues on towards the front glass surface, a portion of the screen-transmitted beam splits at the window surface into transmitted and reflected components. The reflected component reflects off the front surface of the glass material ($T_{sc}^{dir,dir} R_{gl,f}^{dir}$) and the transmitted component continues to travel through the glass material and is further attenuated by the glass beam transmittance. Thus the first term of the combined screen/glass solar beam transmittance is shown as $T_{sc}^{dir,dir} T_{gl}^{dir}$. Interreflections are accounted for by following the beam as it continues to reflect off the front surface of the glass material and the back surface of the screen material. Continuing on with the glass-reflected beam ($T_{sc}^{dir,dir} R_{gl,f}^{dir}$) described above, this beam strikes the back surface of the screen material at the same incident angle as the incident solar beam. This reflected beam is also assumed to be a collimated beam (solid lines) which strikes the back surface of the screen material and reflects as hemispherically-diffuse radiation (dotted lines). The reflective property of the screen material used here is the beam reflectance calculated at the incident solar angle ($R_{sc}^{dir,dif}$). A single ray of this diffuse light will be followed through the remaining steps and represents the energy associated with **<u>all</u>** diffuse rays interreflecting between the screen and glass layers. To determine the second term of the combined screen/glass beam transmittance, the diffusely-reflected ray ($T_{sc}^{dir,dir} R_{gl,f}^{dir} R_{sc}^{dir,dif}$) passes through and is attenuated by the glass layer. Since this ray originates from diffuse reflection, the attenuation of this ray is accounted for using the diffuse transmittance property of the glass. Thus, the second term is shown as $T_{sc}^{dir,dir} R_{gl,f}^{dir} R_{sc}^{dir,dif} T_{gl}^{dif}$. Defining the remaining terms continues in a similar fashion using diffuse properties of both the screen and glass material. Notice that the 3rd and 4th terms shown below are similar to the 2nd term, but additional terms are raised to increasing powers.



$$T_{sc}^{dir} = T_{sc}^{dir,dir}$$
$$R_{sc}^{dir} = R_{sc}^{dir,dif}$$
$$R_{sc}^{dif} = R_{sc}^{dif,dif}$$

Figure 11. Screen/Glass System Transmittance Equation Schematic.

The screen/glass system transmittance equation shown in the figure above is repeated here in an alternate format to emphasize the recurring nature of the infinite series. This equation represents the final solar beam transmittance equation for the screen/glass combination. The recurring terms are shown as a summation of a quantity raised to the n power, with n ranging from 0 to infinity. Since the quantity $R_{gl}^{dif} R_{sc}^{dif,dif}$ is less than 1, the summation $\sum_{n=0}^{\infty}(R_{gl,f}^{dif} R_{sc}^{dif,dif})^n$ converges and can be expressed as $1 \big/ \left(1 - R_{gl,f}^{dif} R_{sc}^{dif,dif}\right)$. Since the reflected (scattered) transmittance of incident solar beam ($T_{sc}^{dir,dif}$) and the diffusely reflecting beam $T_{sc}^{dir,dir} R_{gl,f}^{dir} R_{sc}^{dir,dif}$ are both assumed to be hemispherically diffuse radiation, the reflected (scattered) transmittance of incident solar beam is added to the infinite series as shown below.

$$T_{sys}^{dir,all}(\alpha',\varphi',\phi) = T_{sc}^{dir,dir}(\alpha',\varphi')T_{gl}^{dir}\left(\phi\right) + (T_{sc}^{dir,dir}(\alpha',\varphi')R_{gl,f}^{dir}R_{sc}^{dir,dif}(\alpha',\varphi') + T_{sc}^{dir,dif}(\alpha',\varphi'))T_{gl}^{dif}\sum_{n=0}^{\infty}(R_{gl,f}^{dif}R_{sc}^{dif,dif})^n$$

$$-or-$$

$$T_{sys}^{dir,all}(\alpha',\varphi',\phi) = T_{sc}^{dir,dir}(\alpha',\varphi')T_{gl}^{dir}\left(\phi\right) + \frac{(T_{sc}^{dir,dir}(\alpha',\varphi')R_{gl,f}^{dir}R_{sc}^{dir,dif}(\alpha',\varphi') + T_{sc}^{dir,dif}(\alpha',\varphi'))T_{gl}^{dif}}{1 - R_{gl,f}^{dif}R_{sc}^{dif,dif}}$$

where

$T_{sys}^{dir,all}(\alpha',\varphi',\phi)$ = screen/glass system beam transmittance (output report variable Screen/Glass System Beam-Beam Solar Transmittance)

Properties for beam absorptance of the individual glass layers and screen/glass combination are derived in a similar fashion to the transmittance calculation described above. Diffuse transmittance and absorptance of individual glass layers and the screen/glass combination are also shown here.

$$A_{gl,j,f}^{dir,sys}\left(\alpha',\varphi',\phi\right) = T_{sc}^{dir,dir}\left(\alpha',\varphi'\right)A_{gl,j,f}^{dir}\left(\phi\right) + \frac{\left(T_{sc}^{dir,dir}\left(\alpha',\varphi'\right)R_{gl}^{dir}\left(\phi\right)R_{sc}^{dir,dif}\left(\alpha',\varphi'\right) + T_{sc}^{dir,dif}\left(\alpha',\varphi'\right)\right)A_{gl,j,f}^{dif}}{1 - R_{gl,f}^{dif}R_{sc}^{dif,dif}}, \; j = 1, N$$

$$\alpha_{sc}^{dir,sys}\left(\alpha',\varphi',\phi\right) = A_{sc}^{dir}\left(\alpha',\varphi'\right)\left(1 + R_{gl,f}^{dir}\left(\phi\right)T_{sc}^{dir,dir}\left(\alpha',\varphi'\right)\right) + \frac{A_{sc}^{dif}R_{gl,f}^{dif}}{1 - R_{sc}^{dif,dif}R_{gl,f}^{dif}}\left(R_{gl,f}^{dir}\left(\phi\right)T_{sc}^{dir,dir}\left(\alpha',\varphi'\right)R_{sc}^{dir,dif}\left(\alpha',\varphi'\right)\right)$$

$$T_{sys}^{dif,dif} = \frac{T_{sc}^{dif,dif}T_{gl}^{dif}}{1 - R_{gl,f}^{dif}R_{sc}^{dif,dif}}$$

$$A_{gl,j,f}^{dif,sys} = \frac{T_{sc}^{dif,dif}A_{gl,j,f}^{dif}}{1 - R_{gl,f}^{dif}R_{sc}^{dif,dif}}, \; j = 1, N$$

$$\alpha_{sc}^{dif,sys} = A_{sc}^{dif}\left(1 + \frac{T_{sc}^{dif,dif}R_{gl,f}^{dif}}{1 - R_{gl,f}^{dif}R_{sc}^{dif,dif}}\right)$$

where

$A_{gl,j,f}^{dir,sys}\left(\alpha',\varphi',\phi\right)$ = glass layer beam absorptance including interreflections with screen material

$\alpha_{sc}^{dir,sys}\left(\alpha',\varphi',\phi\right)$ = beam absorptance of screen material including interreflections with glass

$T_{sys}^{dif,dif}$ = screen/glass system diffuse transmittance (output report variable Screen/Glass System Diffuse-Diffuse Solar Transmittance)

$A_{gl,j,f}^{dif,sys}$ = glass layer diffuse absorptance including interreflections with screen material

$\alpha_{sc}^{dif,sys}$ = diffuse absorptance of screen material including interreflections with glass

Screen/Glazing System Properties for Long-Wave Radiation

The program calculates how much long-wave radiation is absorbed by the screen and by the adjacent glass surface. The effective long-wave emissivity (equal to the long-wave absorptance on a wavelength-by-wavelength basis or over the same spectral range) of an exterior screen, taking into account reflection of long-wave radiation between the glass and screen, is given by

$$\varepsilon_{sc}^{lw,eff} = \varepsilon_{sc}^{lw}\left(1 + \frac{T_{sc}^{dif,dif}\rho_{gl}^{lw}}{1 - R_{sc}^{dif,dif}\rho_{gl}^{lw}}\right)$$

where ρ_{gl}^{lw} is the long-wave reflectance of the outermost glass surface facing an exterior screen, and it is assumed that the long-wave transmittance of the glass is zero.

The effective outermost (for exterior screen) glass surface emissivity when the screen is present is

$$\varepsilon_{gl}^{lw,eff} = \varepsilon_{gl}^{lw}\frac{T_{sc}^{dif,dif}}{1 - R_{sc}^{dif,dif}\rho_{gl}^{lw}}$$

The effective inside surface emissivity is the sum of the effective screen and effective glass emissivities:

$$\varepsilon_{ins}^{lw,eff} = \varepsilon_{sc}^{lw,eff} + \varepsilon_{gl}^{lw,eff}$$

The effective temperature of the screen/glazing combination that is used to calculate the window's contribution to the zone's mean radiant temperature (MRT) is given by

$$T^{eff} = \frac{\varepsilon_{sc}^{lw,eff}T_{sc} + \varepsilon_{gl}^{lw,eff}T_{gl}}{\varepsilon_{sc}^{lw,eff} + \varepsilon_{gl}^{lw,eff}}$$

Solar Radiation Transmitted and Absorbed by a Window/Screen System

Let the direct solar incident on the window be

$$I_{dir,inc} = f_{sunlit}I_{dir,norm}\cos\phi \quad (W/m^2)$$

where f_{sunlit} is the fraction of the window that is sunlit (determined by the shadowing calculations), $I_{dir,norm}$ is the direct normal solar irradiance, and ϕ is the angle of incidence.

Let $I_{sky,inc}$ be the irradiance on the window due to diffuse solar radiation from the sky (W/m^2) and let $I_{gnd,inc}$ be the irradiance on the window due to diffuse solar radiation from the ground (W/m^2).

Then we have the following expressions for different classes of transmitted and absorbed solar radiation for the window/screen system, all in W/m^2:

Direct and diffuse solar entering zone from incident direct solar:

$$I_{dir,inc} T_{sys}^{dir,all}\left(\alpha', \varphi'\right)$$

Direct solar absorbed by screen:

$$I_{dir,inc} \alpha_{sc}^{dir,sys}\left(\alpha', \varphi'\right)$$

Direct solar absorbed by glass layers:

$$I_{dir,inc} A_{gl,j,f}^{dir,sys}(\phi, \phi_s), \quad j = 1, N$$

Diffuse solar entering zone from incident diffuse solar:

$$\left(I_{sky,inc} + I_{gnd,inc}\right) T_{sys}^{dif,dif}$$

Diffuse solar absorbed by screen:

$$\left(I_{sky,inc} + I_{gnd,inc}\right) \alpha_{sc}^{dif,sys}$$

Diffuse solar absorbed by glass layers:

$$(I_{sky,inc} + I_{gnd,inc}) A_{gl,j,f}^{dif,sys}, \quad j = 1, N$$

Reference Input Data Set for Material:WindowScreen

```
MATERIAL:WindowScreen,
  CHARCOAL FIBERGLASS SCREEN 1, !- Name
  Model As Diffuse,             !- Reflected Beam Transmittance Accounting Method
  0.08,                         !- Diffuse Solar Reflectance
  0.08,                         !- Diffuse Visible Reflectance
  0.9,                          !- Thermal Hemispherical Emissivity
  0.04,                         !- Conductivity {W/m-K}
  0.00157,                      !- Screen Material Spacing {m}
  0.000381,                     !- Screen Material Diameter {m}
  0.025,                        !- Screen-to-Glass Distance {m}
  0.0,                          !- Top Opening Multiplier
  0.0,                          !- Bottom Opening Multiplier
  0.0,                          !- Left-Side Opening Multiplier
  0.0,                          !- Right-Side Opening Multiplier
  0;                            !- Angle of Resolution for Screen Transmittance
                                   Output Map

MATERIAL:WindowScreen,
  CHARCOAL FIBERGLASS SCREEN 2, !- Name
  Model As Diffuse,             !- Reflected Beam Transmittance Accounting Method
  0.08,                         !- Diffuse Solar Reflectance
  0.08,                         !- Diffuse Visible Reflectance
  0.9,                          !- Thermal Hemispherical Emissivity
  0.04,                         !- Conductivity {W/m-K}
  0.00167,                      !- Screen Material Spacing {m}
  0.000381,                     !- Screen Material Diameter {m}
  0.025,                        !- Screen-to-Glass Distance {m}
  0.0,                          !- Top Opening Multiplier
  0.0,                          !- Bottom Opening Multiplier
  0.0,                          !- Left-Side Opening Multiplier
  0.0,                          !- Right-Side Opening Multiplier
  0;                            !- Angle of Resolution for Screen Transmittance
                                   Output Map

MATERIAL:WindowScreen,
  CHARCOAL FIBERGLASS SCREEN 3, !- Name
  Model As Diffuse,             !- Reflected Beam Transmittance Accounting Method
  0.08,                         !- Diffuse Solar Reflectance
  0.08,                         !- Diffuse Visible Reflectance
  0.9,                          !- Thermal Hemispherical Emissivity
  0.04,                         !- Conductivity {W/m-K}
  0.00155,                      !- Screen Material Spacing {m}
  0.000406,                     !- Screen Material Diameter {m}
  0.025,                        !- Screen-to-Glass Distance {m}
  0.0,                          !- Top Opening Multiplier
  0.0,                          !- Bottom Opening Multiplier
  0.0,                          !- Left-Side Opening Multiplier
  0.0,                          !- Right-Side Opening Multiplier
  0;                            !- Angle of Resolution for Screen Transmittance
                                   Output Map

MATERIAL:WindowScreen,
  BRIGHT ALUMINUM SCREEN 1,     !- Name
  Model As Diffuse,             !- Reflected Beam Transmittance Accounting Method
  0.6,                          !- Diffuse Solar Reflectance
  0.6,                          !- Diffuse Visible Reflectance
  0.9,                          !- Thermal Hemispherical Emissivity
  221.0,                        !- Conductivity {W/m-K}
  0.00154,                      !- Screen Material Spacing {m}
  0.000254,                     !- Screen Material Diameter {m}
  0.025,                        !- Screen-to-Glass Distance {m}
  0.0,                          !- Top Opening Multiplier
  0.0,                          !- Bottom Opening Multiplier
```

```
  0.0,                              !- Left-Side Opening Multiplier
  0.0,                              !- Right-Side Opening Multiplier
  0;                                !- Angle of Resolution for Screen Transmittance
                                       Output Map

MATERIAL:WindowScreen,
  BRIGHT ALUMINUM SCREEN 2,         !- Name
  Model As Diffuse,                 !- Reflected Beam Transmittance Accounting Method
  0.6,                              !- Diffuse Solar Reflectance
  0.6,                              !- Diffuse Visible Reflectance
  0.9,                              !- Thermal Hemispherical Emissivity
  221.0,                            !- Conductivity {W/m-K}
  0.00164,                          !- Screen Material Spacing {m}
  0.000254,                         !- Screen Material Diameter {m}
  0.025,                            !- Screen-to-Glass Distance {m}
  0.0,                              !- Top Opening Multiplier
  0.0,                              !- Bottom Opening Multiplier
  0.0,                              !- Left-Side Opening Multiplier
  0.0,                              !- Right-Side Opening Multiplier
  0;                                !- Angle of Resolution for Screen Transmittance
                                       Output Map
```

Appendix D

EnergyPlus Documentation for Modeling Energy Losses Related to Building Air Distribution Systems

This appendix contains the EnergyPlus documentation (Input/Output Reference and Engineering Manual sections) that describes the Airflow Network model added as part of this project.

Input Output Reference for AirflowNetwork Model

Overview

The AirflowNetwork model provides the ability to simulate the performance of a central forced air distribution system, and calculates multizone airflows driven by wind and forced air distribution that occur during HVAC system fan operation. This model can also calculate multizone airflows driven by wind when the HVAC system fan is off or when no forced air distribution system is specified for the simulation. When modeling an air distribution system, the current version of the AirflowNetwork model is restricted to a single central forced air system (AIR PRIMARY LOOP object) which uses a constant volume fan. The capabilities of the model are to:

- Simulate zone pressures due to envelope leakage and forced air distribution during HVAC system fan operation
- Simulate node pressures in a forced air distribution system during HVAC system fan operation
- Calculate multizone airflows due to forced air, wind, and surface leakage, including adjacent zones and outdoors, during HVAC system fan operation
- Simulate distribution system airflows, including supply and return air leaks, during HVAC system fan operation
- Simulate air distribution system node temperatures and humidity ratios during HVAC system fan operation
- Calculate duct conduction losses during HVAC system fan operation
- Calculate vapor diffusion losses of ducts during HVAC system fan operation
- Calculate sensible and latent loads on the surrounding zones due to supply and return air leaks in the air distribution system during HVAC system fan operation
- Simulate zone pressures due to envelope leakage driven by wind when the HVAC system fan is off or if no air distribution system is specified
- Calculate multizone airflows due to wind and surface leakage, including adjacent zones and outdoors when the HVAC system fan is off or if no air distribution system is specified

Input differences between COMIS and AirflowNetwork models

The AirflowNetwork model encompasses the capabilities that were previously available through the EnergyPlus/COMIS link. The one exception is that the AirflowNetwork model can only have one airflow crack per heat transfer surface and either one airflow crack or one opening per heat transfer subsurface (the COMIS link allowed multiple cracks and/or openings). The input differences between the previous COMIS model and the new AirflowNetwork model are minor. The main difference is object names. Differences also occur for the input requirements between the COMIS Simulation object and the AirflowNetwork Simulation object. Conversion from COMIS to AirflowNetwork is straightforward and can be completed using the transition program included with EnergyPlus. The transition program assists users in converting COMIS model objects contained in existing input data files to the new objects required for the AirflowNetwork model. For the V1.3 release, some internal transitions are done with the resultant IDF portions being written to the .audit file – these internal transitions will be removed in the next release – so please create your new input files. Report variables previously used with COMIS were renamed to similar AirflowNetwork report variables.

Input differences between ADS and AirflowNetwork models

The AirflowNetwork model also encompasses the capabilities that were previously modeled through air distribution system (ADS) objects. There are many input object and structure changes for the AirflowNetwork model compared to the previous ADS model, although the main functionalities are quite similar. The following summary compares the differences in the Node, Element, and Linkage structures for the old ADS model and the new AirflowNetwork model.

Node Structure:

The ADS model defined all nodes using the ADS Node Data object, including nodes in an air distribution system, external nodes, and thermal zone nodes. The AirflowNetwork model divides these nodes into three different input objects: AirflowNetwork:Multizone:Zone, AirflowNetwork:Multizone:External Node, and AirflowNetwork:Distribution:Node. The new input structure has the following advantages:

- It is not necessary to distinguish which type of node is represented as was done in the ADS Node Data object. The new input objects clearly represent what type of node is being specified and provides a better representation of node connections for the user.
- The previous method used COMIS to calculate multizone airflow when the HVAC system fan was off (or when no air distribution system was specified) and ADS to calculate multizone airflow when the HVAC system fan was on. The AirflowNetwork model can perform either multizone airflow calculations driven by wind only (air distribution system specified but HVAC system fan off, or no air distribution system specified), or driven by wind and forced air (air distribution system specified and HVAC system fan on).

Element Structure:

The ADS model combined all element types together in a single ADS Element Data object. Different element types required different input to establish a relationship between pressure and airflow, and the ADS Element Data object used a key word (Field 2 in the ADS Element Data object) to distinguish what type of element it was. “Elements” in the ADS model are called “components” in the AirflowNetwork model. The AirflowNetwork model requires that each type of component have its own object. For example, an element of “PLR” (Field 2) in ADS Element Data has a specific object name in the new model: AirflowNetwork:Distribution:Component Leak. An element of “DWC” in ADS Element Data now has its own specific name in the new model: AirflowNetwork:Distribution:Component Duct. The required number of fields for each object is fixed. Therefore, the user does not need to remember how many fields are needed for each component in the new AirflowNetwork model. The main concern when revising the structure was to make inputs for each type of component as specific as possible, and limit any confusion.

Linkage Structure:

The ADS model had an ADS Linkage Data object to provide all necessary links between two nodes and an element. The ADS model did not distinguish whether a linkage belonged to envelope leakage or a duct connection. The new AirflowNetwork model has two types of linkages: Surface and Distribution. The new object for surface linkage is AirflowNetwork:Multizone:Surface, which provides an external node (for exterior surface only), a zone node, and an associated component, or two zone nodes (for interior surface) and an associated component. The new object for distribution linkage is AirflowNetwork:Distribution:Linkage, which provides the connection for two air distribution system nodes and an associated component.

Summary of Objects

Before describing the AirflowNetwork input objects in detail, we list all of the objects and then give a short description of what the objects do.

The AirflowNetwork input objects are:

AirflowNetwork Simulation
AirflowNetwork:Multizone:Zone
AirflowNetwork:Multizone:Surface
AirflowNetwork:Multizone:Component Simple Opening
AirflowNetwork:Multizone:Component Detailed Opening

AirflowNetwork:Multizone:Surface Crack Data
AirflowNetwork:Multizone:Reference Crack Conditions
AirflowNetwork:Multizone:Surface Effective Leakage Area
AirflowNetwork:Multizone:Site Wind Conditions
AirflowNetwork:Multizone:External Node
AirflowNetwork:Multizone:Wind Pressure Coefficient Array
AirflowNetwork:Multizone:Wind Pressure Coefficient Values
AirflowNetwork:Distribution:Node
AirflowNetwork:Distribution:Component Leak
AirflowNetwork:Distribution:Component Leakage Ratio
AirflowNetwork:Distribution:Component Duct
AirflowNetwork:Distribution:Component Constant Pressure Drop
AirflowNetwork:Distribution:Component Constant Volume Fan
AirflowNetwork:Distribution:Component Coil
AirflowNetwork:Distribution:Component Terminal Unit
AirflowNetwork:Distribution:Linkage

- **AirflowNetwork Simulation** defines basic run parameters for the air flow calculations and specifies whether wind pressure coefficients are input by the user or, for rectangular buildings, calculated by the program.
- The **AirflowNetwork:Multizone:Zone** object specifies the ventilation control that applies to all of the openable exterior and interior windows and doors in the corresponding thermal zone. Surface-level ventilation control can be used to override the zone-level ventilation control if required (see AirflowNetwork: Multizone:Surface object below).
- **AirflowNetwork:Multizone:Surface** object indicates whether a heat transfer surface (wall, window, etc.) has a crack or opening and references an **AirflowNetwork:Multizone:Surface Crack Data, AirflowNetwork:Multizone:Surface Effective Leakage Area, AirflowNetwork:Multizone: Component Simple Opening, or AirflowNetwork:Multizone:Component Detailed Opening** object that gives the air flow characteristics of that crack or opening. The AirflowNetwork:Multizone:Surface object can also be used to specify individual ventilation control for openable exterior and interior windows and doors.
- **AirflowNetwork:Multizone:Reference Crack Conditions** is used to normalize crack information that is based on measurements of crack air flow.
- **AirflowNetwork:Distribution:Node** represents air distribution system nodes for the AirflowNetwork model. A set of an Air Primary Loop and Zone Equipment Loop nodes is a subset of the AirflowNetwork:Distribution:Nodes.
- **AirflowNetwork:Distribution:Component** objects consist of **Leak, Leakage Ratio, Duct, Constant Pressure Drop, Constant Volume Fan, Coil,** and **Terminal Unit.** The components provide a relationship between pressure and airflow. The **Leak** and **Leakage** components can be used to simulate supply and/or return leaks in an air distribution system**.** The **Duct** and **Constant Pressure Drop components** can be used to deliver forced air into conditioned spaces. The components **Constant Volume Fan, Coil, and Terminal Unit** are regular EnergyPlus objects. The AirflowNetwork model gets information from these objects to perform an airflow network simulation.
- **AirflowNetwork:Distribution:Linkage** object represents a connection between two node objects and an AirflowNetwork component. The node objects can be an AirflowNetwork:Distribution:Node, AirflowNetwork:Multizone:External Node or AirflowNetwork:Multizone:Zone.

If you input wind pressure coefficients, **AirflowNetwork:Multizone:Surface** also has an associated **AirflowNetwork:Multizone:External Node**, that, via the **AirflowNetwork:Multizone:Site Wind Conditions**, **AirflowNetwork:Multizone: Wind Pressure Coefficient Array** and **AirflowNetwork:Multizone:Wind Pressure Coefficient Values** objects, gives the wind pressure distribution vs. wind direction for that node and, implicitly, for the cracks and openings in the exterior surfaces associated with that node.

Figure 12 shows the relationship among AirflowNetwork:Multizone objects and between AirflowNetwork:Multizone objects and regular EnergyPlus objects. In this figure an arrow from object A to object B means A references B, i.e., one of the inputs in A is the name of object B. For example, one input for AirflowNetwork: Multizone:Surface is the name of a heat transfer surface, and another is the name of a crack or opening object. The arrow between AirflowNetwork:Multizone:Surface and AirflowNetwork:Multizone:External Node is shown dashed to indicate that this. reference is not used when wind pressure coefficients are calculated by the program rather than being input by the user.

Figure 12 also shows the relationship among AifrlowNetwork:Distribution objects and between AifrlowNetwork:Distribution objects and regular EnergyPlus objects. The AirflowNetwork:Distribution:Linkage objects link two nodes from objects AirflowNetwork:Distribution:Node and AirflowNetwork:Multizone:Zone and a component defined in the object AirflowNetwork:Distribution:Component. The solid arrows show a reference from object A to object B. The dashed arrows indicate any one of the components, which can be used as a component in a linkage object. The red arrows pointed to Zone indicate the components interact with the zone. For example, the temperature in a zone where a supply leak terminates is used to calculate duct leakage energy loss. The temperature in a zone where a duct component is located is also used to calculate duct conduction loss.

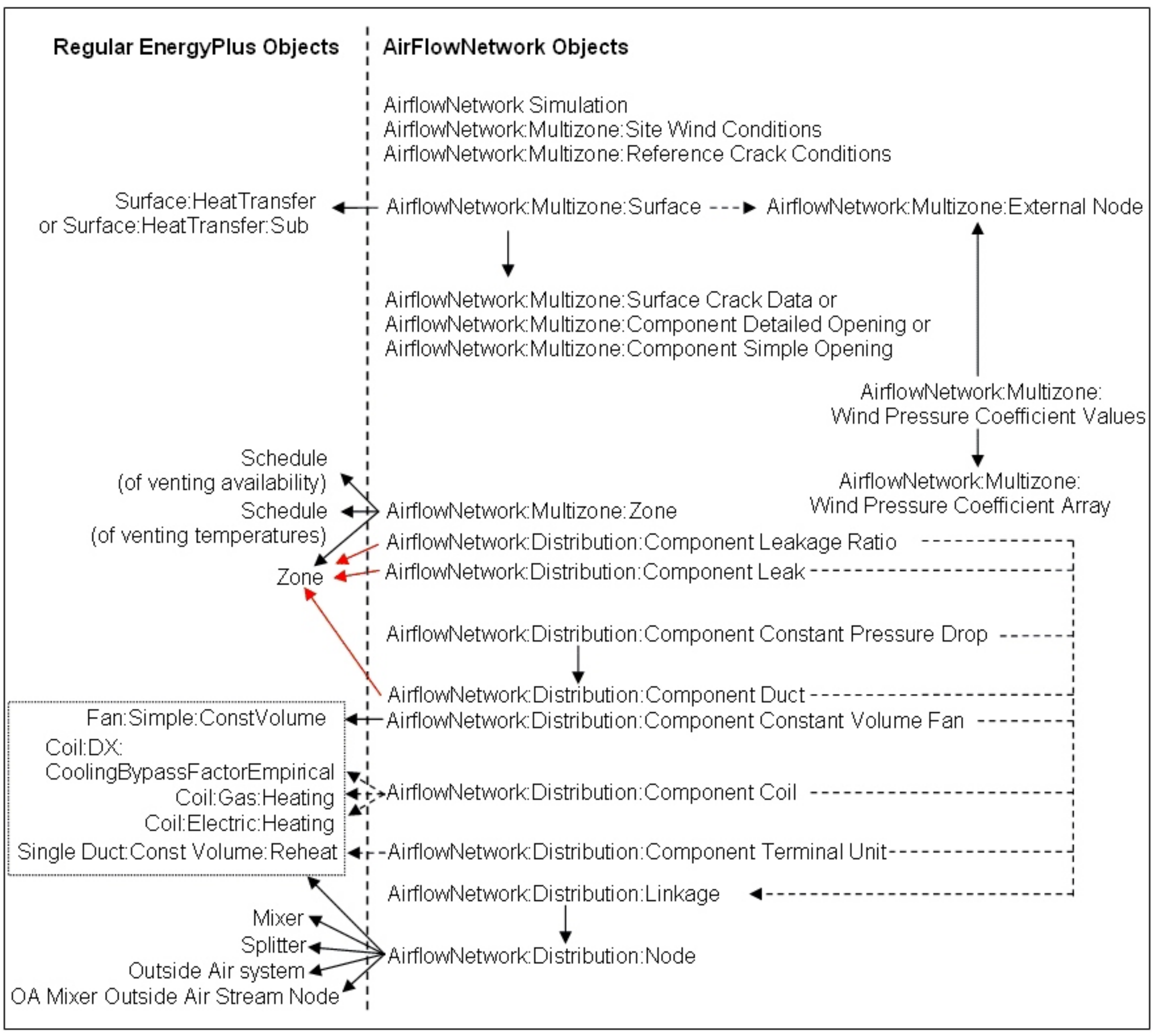


Figure 12. Relationship among AirflowNetwork objects (right-hand side) and between AirflowNetwork objects and regular EnergyPlus objects. An arrow from object A to object B means that A references B.

Much of the information needed for the air flow calculation is automatically extracted from the building description for thermal modeling. This includes things like the volume and neutral height of the zones, and the orientation and location of the building surfaces that contain cracks or openings through which air flows. From all of this information the program creates a "pressure-flow network" that is solved each time step using iterative solution methods to obtain the unknown pressures and air flows.

Figure 13 shows a plan view of a very simple air flow network that you can construct using the above AirflowNetwork objects. There are three thermal zones, Zone-1, Zone-2 and Zone-3. There are openable exterior windows—Window-1, Window-2 and Window-3—and openable interior doors—Door-12 and Door-23. Two External Nodes are indicated. ExternalNode-1 is associated with the façade that contains Window-1 and Window-2. ExternalNode-2 is associated with the façade containing Window-3.

One possible air flow pattern is shown in this figure. The actual air flow pattern in a particular time step, and the size of the flows, depends on many factors, such as (1) What is the wind pressure distribution seen by the exterior windows? (2) Are the exterior windows and doors open or closed, and if open, how far are they open? (3) Are the interior windows and doors open or closed? (4) What are the air temperature differences between zones and between zones and the outside air (which affect buoyancy flows)?

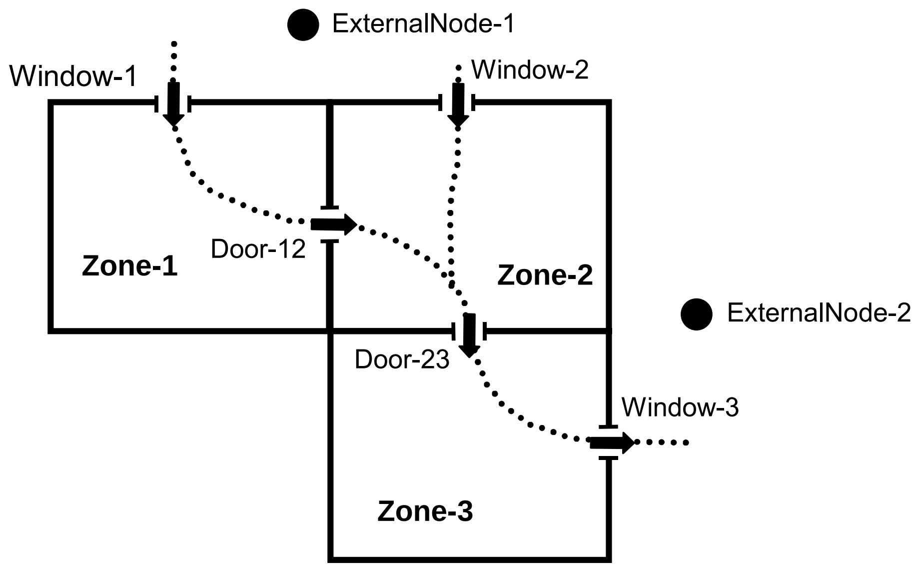


Figure 13. Plan view of a simple air flow network showing a possible air flow pattern in which all of the windows and doors are open.

Figure 13 shows a possible air flow pattern in which all of the windows and doors are open. Associated with the external nodes are wind pressure distributions as a function of wind direction that are input using two AirflowNetwork:Multizone:Wind Pressure Coefficient Values objects. The nature of the air flows through the windows and doors is specified using AirflowNetwork:Multizone:Component Detailed Opening and AirflowNetwork:Multizone:Component Simple Opening objects. The AirflowNetwork model calculates the flows each system time step depending on various factors, including wind direction and speed, size and vertical position of openings, outside air temperature, and zone air temperatures.

AirflowNetwork Example Files

AirflowNetwork3zVent.idf

AirflowNetwork3zVentAutoWPC.idf

AirflowNetwork_Simple_House.idf

AirflowNetwork_Simple_SmallOffice.idf

AirflowNetwork_Multizone_House.idf

AirflowNetwork_Multizone:SmallOffice.idf

CrossVent_1Zone_AirlfowNetwork.idf

DisplacementVent_Nat_AirflowNetwork.idf

What AirflowNetwork model Can and Cannot Do

Here is a list of some of the things that the AirflowNetwork calculation can and cannot model.

Can Do

1) Air flow through cracks in exterior or interzone surfaces.
2) Air flow through cracks around windows and doors when closed.
3) Natural ventilation (i.e., air flow through open or partially open exterior windows and doors).
4) Zone level control of natural ventilation (all windows/doors in a zone that are defined with a component opening object have identical controls).
5) Individual surface control of natural ventilation for a subsurface (window, door, or glassdoor).
6) Modulation of natural ventilation to prevent large zone air temperature swings.
7) Interzone air flow (i.e., air flow through open interzone windows and doors, and through cracks in interzone surfaces).
8) Dependence of air flow on buoyancy effects and wind pressure.
9) Dependence of wind pressure on wind speed, wind direction and surface orientation.
10) Supply and return air leaks in an air distribution system.
11) Account for the effect of supply-air and/or return-air leakage on zone pressure when a forced air distribution system is present and is operating.
12) When duct leakage is modeled and the HVAC system is on, interzone airflow or infiltration/exfiltration can occur due to changes in zone pressure.
13) Bi-directional flow through large vertical openings. See discussion below under AirflowNetwork:Multizone:Component Detailed Opening and AirflowNetwork: Multizone:Component Simple Opening.
14) Calculate air flows and pressures in ducts or other components of a forced air distribution system.

Cannot Do or Restricted

1) The model is restricted to using a constant volume fan (Fan:Simple: ConstVolume) and can not model variable volume fan equipment.
2) Air circulation and/or air temperature stratification within a thermal zone. For example, you should not try to divide a high space, such as an atrium, into subzones separated by artificial horizontal surfaces that have cracks or openings with the expectation that AirflowNetwork will give you a realistic temperature in each subzone and/or a realistic air flow between subzones.
3) The model is restricted to three types of coils (Coil:DX:CoolingBypassFactorEmpirical, Coil:Gas:Heating, Coil:Electric:Heating).
4) The model is restricted to one type of terminal unit (Single Duct:Const Volume:Reheat).
5) Pollutant transport is not available.
6) Supply and return leaks are not allowed in an Air Primary Loop. They can only be modeled in the Zone Equipment Loop (i.e., return leaks may be modeled between the zone return node and the zone mixer inlet or the zone mixer outlet and the zone equipment loop outlet; and supply leaks may be modeled between the zone equipment loop inlet and the zone splitter inlet node or the zone splitter outlet node and the zone supply node).
7) An air distribution system must be located inside the building (i.e. the ducts must pass through zones within the building).

The input specifications consist of five main sections: **AirflowNetwork simulation object, AirflowNetwork multizone data objects, AirflowNetwork node data objects, AirflowNetwork component data objects,** and **AirflowNetwork linkage data object.** Each of these object types is described in detail below.

AirflowNetwork Simulation

The basic run parameters for this model are defined in this unique object which has the following input specifications:

Field: AirflowNetwork Simulation Name

This is a unique character string associated with this instance of the AIRFLOWNETWORK SIMULATION object. At this time, only one AIRFLOWNETWORK SIMULATION object can be specified in an input data file (idf).

Field: AirflowNetwork Control

The following selections are available to control the AirflowNetwork simulation:

Multizone with Distribution: Multizone air flow calculations are performed during all simulation time steps, including the impacts of the air distribution system when a HVAC system fan is operating. Any INFILTRATION, VENTILATION, MIXING and CROSS MIXING objects specified in the input data file are not simulated.

Multizone without Distribution: Multizone air flow calculations are performed during all simulation time steps, but the air distribution system portion of the network is not modeled even if it is specified in the input data file. Any INFILTRATION, VENTILATION, MIXING and CROSS MIXING objects specified in the input data file are not simulated.

Multizone with Distribution Only During Fan Operation: Multizone air flow calculations, including the impacts of the air distribution system, are only performed when the HVAC system fan is operating. Any INFILTRATION, VENTILATION, MIXING and CROSS MIXING objects specified in the input data file are used when the HVAC system fan is OFF (if none are specified, then no air flow calculations are performed when the fan is OFF).

No Multizone or Distribution: No multizone air flow calculations (with or without the air distribution system portion of the network) are performed during the simulation. Any INFILTRATION, VENTILATION, MIXING and CROSS MIXING objects specified in the input data file are simulated (if none are specified, then no air flow calculations are performed). Note: Having an input data file with no AIRFLOWNETWORK SIMULATION objects gives the same impact – no multizone air flow calculations. However, this choice is provided as a convenience to the user to easily disable the multizone air flow calculations for an input data file that already contains AirflowNetwork objects.

Field: Wind Pressure Coefficient Type

Determines whether the wind pressure coefficients are input by the user or calculated. The choices are INPUT or SURFACE-AVERAGE CALCULATION, with the default being SURFACE-AVERAGE CALCULATION.

If INPUT, you must enter an AirflowNetwork:Multizone:Wind Pressure Coefficient Array object, one or more AirflowNetwork:Multizone:External Node objects, and one or more AirflowNetwork:Multizone:Wind Pressure Coefficient Values objects.

The second choice, SURFACE-AVERAGE CALCULATION, should only be used for **rectangular** buildings. In this case surface-average wind pressure coefficients vs. wind direction are calculated by the program for the four vertical facades and the roof based on user entries for "Building Type," "Azimuth Angle of Long Axis of Building," and "Ratio of Building Width Along Short Axis to Width Along Long Axis" (see description of these fields below). With this choice you do **not** have to enter any of the following objects: AirflowNetwork:MultiZone: Wind Pressure Coefficient Array, AirflowNetwork:MultiZone:External Node and AirflowNetwork:MultiZone:Wind Pressure Coefficient Values.

Field: AirflowNetwork Wind Pressure Coefficient ARRAY Name

This is the name of the AirflowNetwork:MultiZone:Wind Pressure Coefficient Array object that contains wind directions corresponding to the wind pressure coefficients given in the AirflowNetwork:MultiZone:Wind Pressure Coefficient Values objects.

Used only if Wind Pressure Coefficient Type = INPUT (see description of previous field).

Field: Building Type

Used only if Wind Pressure Coefficient Type = SURFACE-AVERAGE CALCULATION. The choices for Building Type are LOWRISE and HIGHRISE, with the default being LOWRISE.

LOWRISE corresponds to a rectangular building whose height is less than three times the width of the footprint (w_{short} in Figure 14) and is less than three times the length of the footprint (w_{long} in the same figure).

HIGHRISE corresponds to a rectangular building whose height is more than three times the width of the footprint (w_{short} in Figure 14) or is more than three times the length of the footprint (w_{long} in the same figure).

Field: Maximum Number of Iterations

The maximum number of iterations allowed in finding an AirflowNetwork solution. If the number of iterations at each simulation time step is above the maximum number of iterations defined by this field, the program could not find the solution and a Severe error is issued and the program is aborted. The default value is 500.

Field: Initialization Type

Designates which method is used for AirflowNetwork initialization. The choices for Initialization Type are Linear Initialization Method and Zero Node Pressures, with the default being Zero Node Pressures.

Field: Relative Airflow Convergence Tolerance

The solution is assumed to have converged when $\left|\sum \dot{m}_i\right| \Big/ \sum\left|\dot{m}_i\right|$ is less than the value specified for this input field. This convergence criteria is equivalent to the ratio of the absolute value of the sum of all network airflows ($\left|\sum \dot{m}_i\right|$) to the sum of network airflow magnitudes ($\sum\left|\dot{m}_i\right|$). The default value is 1.0×10^{-4}.

Field: Absolute Airflow Convergence Tolerance

The solution is assumed to have converged when the summation of the absolute value of all network airflows ($\left|\sum \dot{m}_i\right|$) is less than the value specified for this input field. The default value is 1.0×10^{-6}.

Field: Convergence Acceleration Limit

If the ratio of successive pressure corrections is less than this limit, use Steffensen acceleration algorithm (Ref. AirflowNetwork Model in the EnergyPlus Engineering Reference). The range for this field is -1 to 1, with the default value being -0.5.

Field: Reference Height for Recorded Wind Data

The height at which the wind speeds in the weather file were measured (in meters). Based on this reference height, the AirflowNetwork model develops a wind velocity vs. height profile using a power law function. The default value is 10.0 meters.

Field: Wind Velocity Profile Exponent

The exponent in the power law function that gives wind velocity vs. height above the ground. The default value is 0.14.

Field: Azimuth Angle of Long Axis of Building

Gives the orientation of a rectangular building for calculating wind pressure coefficients. This is the smaller of the angles, measured clockwise, between North and the long axis of the building (see Figure 14). Used only if Wind Pressure Coefficient Type = SURFACE-AVERAGE CALCULATION. The range for this input is 0 to 180, with the default value being 0.

Field: Ratio of Building Width Along Short Axis to Width Along Long Axis

This is the aspect ratio of a rectangular footprint. It is given by the width of the footprint along its short axis divided by the width along the long axis (see Figure 14). If the footprint is square, the value of this field is 1.0. Used only if Wind Pressure Coefficient Type = SURFACE-AVERAGE CALCULATION. The range for this input is > 0 to 1, with the default value being 1.

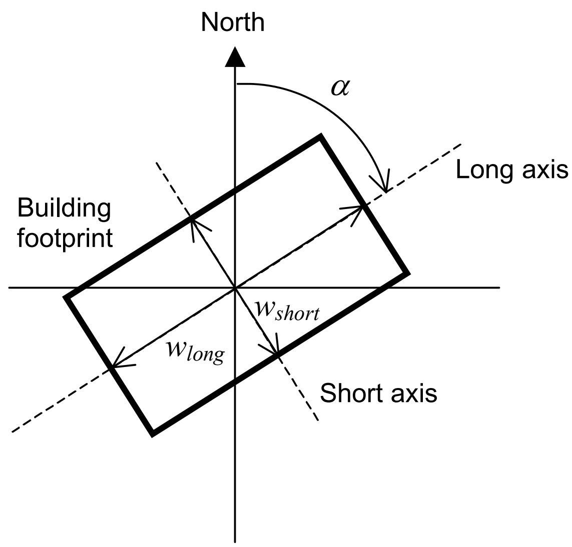


Figure 14. Footprint of a rectangular building showing variables used by the program to calculate surface-average wind pressure coefficients. The angle α is the "Azimuth Angle of Long Axis of Building." w_{short}/w_{long} is the "Ratio of Building Width Along Short Axis to Width Along Long Axis."

Below is the input data dictionary description for the AirflowNetwork Simulation object.

```
AIRFLOWNETWORK SIMULATION,
      \min-fields 14
      \unique-object
      \memo This object defines the global parameters used in an AirFlowNetwork simulation.
 A1 , \field AirflowNetwork Simulation Name
      \required-field
      \note Enter a unique name for this object.
 A2 , \field AirflowNetwork Control
      \type choice
      \key MULTIZONE WITH DISTRIBUTION
      \key MULTIZONE WITHOUT DISTRIBUTION
      \key MULTIZONE WITH DISTRIBUTION ONLY DURING FAN OPERATION
      \key NO MULTIZONE OR DISTRIBUTION
      \default NO MULTIZONE OR DISTRIBUTION
      \note NO MULTIZONE OR DISTRIBUTION: Only perform SIMPLE calculations (objects INFILTRATION,
      \note VENTILATION, MIXING and CROSS MIXING);
      \note MULTIZONE WITHOUT DISTRIBUTION: Use AirflowNetwork objects to simulate multizone
      \note airflows driven by wind during simulation time,
      \note and objects of INFILTRATION, VENTILATION, MIXING and CROSS MIXING are ignored;
      \note MULTIZONE WITH DISTRIBUTION ONLY DURING FAN OPERATION: Perform distribution system
      \note calculations during system fan on time
      \note and SIMPLE calculations during system fan off time;
      \note MULTIZONE WITH DISTRIBUTION: Perform distribution system calculations during system
      \note fan on time and multizone airflow driven by wind during system fan off time.
 A3 , \field Wind Pressure Coefficient Type
      \type choice
      \key INPUT
      \key SURFACE-AVERAGE CALCULATION
      \default SURFACE-AVERAGE CALCULATION
      \note INPUT: User must input AirflowNetwork Wind Pressure Coefficient Array, AirflowNetwork
      \note External Node,
      \note and AirflowNetwork Wind Pressure Coefficient Values objects.
      \note SURFACE-AVERAGE CALCULATION: used only for rectangular buildings.
      \note If SURFACE-AVERAGE CALCULATION is selected,
      \note AirflowNetwork Wind Pressure Coefficient Array, AirflowNetwork External Node,
      \note and AirflowNetwork Wind Pressure Coefficient Values objects are not used.
 A4 , \field AirflowNetwork Wind Pressure Coefficient Array Name
      \type object-list
      \object-list WPCSetNames
      \note Used only if Wind Pressure Coefficient Type = INPUT, otherwise this field may be left
      \note blank.
 A5 , \field Building Type
      \note Used only if Wind Pressure Coefficient Type = SURFACE-AVERAGE CALCULATION,
      \note otherwise this field may be left blank.
      \type choice
      \key LOWRISE
      \key HIGHRISE
      \default LOWRISE
 N1 , \field Maximum number of iterations
      \type integer
      \units dimensionless
      \default 500
      \note Determines the maximum number of iterations used to converge on a solution.
      \note If this limit is exceeded, the program terminates.
 A6 , \field Initialization Type
      \type choice
      \key Linear Initialization Method
      \key Zero Node Pressures
      \default Zero Node Pressures
 N2 , \field Relative airflow convergence tolerance
      \type real
      \units dimensionless
      \default 1.E-4
      \minimum> 0
      \note This tolerance is defined as the absolute value of the sum of the mass flow rates
      \note divided by the sum of the absolute value of the mass flow rates. The mass flow rates
      \note described here refer to the mass flow rates at all nodes in the AirFlowNetwork model.
      \note The solution converges when both this tolerance and the tolerance in the next field
      \note (N4) are satisfied.
 N3 , \field Absolute airflow convergence tolerance
      \type real
      \units kg/s
      \default 1.E-6
      \minimum> 0
      \note This tolerance is defined as the absolute value of the sum of the mass flow rates. The
```

```
      \note mass flow rates
      \note described here refer to the mass flow rates at all nodes in the AirFlowNetwork model.
      \note The solution
      \note converges when both this tolerance and the tolerance in the previous field (N3) are
      \note satisfied.
 N4 , \field Convergence acceleration limit
      \type real
      \units dimensionless
      \note Used only for AirflowNetwork simulation
      \minimum -1
      \maximum 1
      \default -0.5
 N5 , \field Reference height for recorded wind data
      \type real
      \units m
      \default 10
      \note Enter the height at which the wind data were recorded.
 N6 , \field Wind velocity profile exponent
      \type real
      \default .14
      \units dimensionless
      \note Enter the exponent used in the wind velocity profile calculation.
 N7 , \field Azimuth Angle of Long Axis of Building
      \type real
      \units deg
      \minimum 0.0
      \maximum 180.0
      \default 0.0
      \note Degrees clockwise from true North.
      \note Used only if Wind Pressure Coefficient Type = SURFACE-AVERAGE CALCULATION.
 N8 ; \field Ratio of Building Width Along Short Axis to Width Along Long Axis
      \type real
      \minimum> 0.0
      \maximum 1.0
      \default 1.0
      \note Used only if Wind Pressure Coefficient Type = SURFACE-AVERAGE CALCULATION.
```

An IDF example:

```
AIRFLOWNETWORK SIMULATION,
    AriflowNetwork_All,      !- AirflowNetwork Simulation Name
    MULTIZONE WITH DISTRIBUTION,  !- AirflowNetwork Control
    INPUT,                   !- Wind Pressure Coefficient Type
    Every 30 Degrees,        !- AirflowNetwork Wind Pressure Coefficient ARRAY Name
    LOWRISE,                 !- Building Type
    500,                     !- Maximum number of iterations {dimensionless}
    Zero Node Pressures,     !- Initialization Type
    1.0E-05,                 !- Relative airflow convergence tolerance {dimensionless}
    1.0E-06,                 !- Absolute airflow convergence tolerance {kg/s}
    -0.5,                    !- Convergence acceleration limit {dimensionless}
    10.0,                    !- Reference height for recorded wind data {m}
    0.14,                    !- Wind velocity profile exponent {dimensionless}
    0.0,                     !- Azimuth Angle of Long Axis of Building {deg}
    1.0;                     !- Ratio of Building Width Along Short Axis to Width Along Long Axis
```

AirflowNetwork:Multizone data objects are used to calculate multizone airflows. This section describes the input requirements for the following objects:

- AIRFLOWNETWORK:MULTIZONE:ZONE
- AIRFLOWNETWORK:MULTIZONE:SURFACE
- AIRFLOWNETWORK:MULTIZONE:SURFACE CRACK DATA
- AIRFLOWNETWORK:MULTIZONE:REFERENCE CRACK CONDITIONS
- AIRFLOWNETWORK:MULTIZONE:SURFACE EFFECTIVE LEAKAGE AREA
- AIRFLOWNETWORK:MULTIZONE:COMPONENT DETAILED OPENING
- AIRFLOWNETWORK:MULTIZONE:COMPONENT SIMPLE OPENING
- AIRFLOWNETWORK:MULTIZONE:SITE WIND CONDITIONS
- AIRFLOWNETWORK:MULTIZONE:EXTERNAL NODE

- AIRFLOWNETWORK:MULTIZONE:WIND PRESSURE COEFFICIENT ARRAY
- AIRFLOWNETWORK:MULTIZONE:WIND PRESSURE COEFFICIENT VALUES

The AirflowNetwork input requirements are very similar to the obselete COMIS model input requirements. Therefore, users can easily understand any differences if they have used the EnergyPlus/COMIS model before. However, there is one major difference in that all fields related to pollutant information have been removed because there is no pollutant simulation available in the current version of EnergyPlus. In addition, two new objects have been added: AirflowNetwork: Multizone:Component Simple Opening and AirflowNetwork:Multizone:Surface Effective Leakage Area. A detailed description for each of these objects is provided below.

AirflowNetwork:Multizone:Zone

This object allows control of natural ventilation through exterior and interior openings in a zone, where "opening" is defined as an openable window or door. (Note that only window, door or glass door subsurfaces in a zone that are specified using AirflowNetwork:Multizone:Component Detailed Opening or AirflowNetwork: Multizone:Component Simple Opening <u>and</u> have an associated AirflowNetwork: Multizone:Surface object are considered to be openings.) The object is very similar to the obsolete COMIS Zone Data object. The control will be applied in the same way to all of the openings in the zone.

This object is required to perform AirflowNetwork calculations. Note that ventilation control for all openings is provided at the zone level as default and individual ventilation control of a surface opening can be used to override the zone-level control (see the AirflowNetwork:Multizone:Surface object description below).

Field: Name of Associated Thermal Zone

The name of the EnergyPlus thermal zone corresponding to the AirflowNetwork zone.

Field: Ventilation Control Mode

Specifies the type of zone-level natural ventilation control.

Let T_{out} equal the outside air temperature, T_{zone} equal the previous time step's zone air temperature, T_{set} equal the Vent Temperature Schedule value, H_{zone} equal the specific enthalpy of zone air from the previous time step, and H_{out} equal the specific enthalpy of outside air. Then the four allowed choices for Ventilation Control Mode are:

NoVent: All of the zone's openable windows and doors <u>are closed at all times</u> independent of indoor or outdoor conditions. The Venting Availability Schedule is ignored in this case. This is the default value for this field.

Temperature: All of the zone's openable windows and doors are opened if $T_{zone} > T_{out}$ <u>**and**</u> $T_{zone} > T_{set}$ <u>**and**</u> Venting Availability Schedule (see below) allows venting.

Enthalpic: All of the zone's openable windows and doors are opened if $H_{zone} > H_{out}$ <u>**and**</u> $T_{zone} > T_{set}$ <u>**and**</u> Venting Availability Schedule allows venting.

Constant: Whenever this object's Venting Availability Schedule allows venting, all of the zone's openable windows and doors are open, independent of indoor or outdoor conditions. Note that "Constant" here means that the size of each opening is fixed while venting; the air flow through each opening can, of course, vary from timestep to timestep.

Field: Vent Temperature Schedule Name

The name of a schedule of zone air temperature set points that controls the opening of windows and doors in the thermal zone to provide natural ventilation. This setpoint is the temperature above which all the openable windows and doors in the zone will be opened if the conditions described in the previous field Ventilation Control Mode are met.

The Vent Temperature Schedule applies only to windows and doors in the zone that are specified using AirflowNetwork:Multizone:Component Detailed Opening or AirflowNetwork:Multizone:Component Simple Opening and have an associated AirflowNetwork:MultiZone:Surface object.

(The discussion under the field Window/Door Opening Factor in the AirflowNetwork:MultiZone:Surface object describes how the actual opening area of a window or door in a particular time step is determined.)

Modulation of Openings

The following five fields can be used to modulate the window/door openings when Ventilation Control Mode = Temperature or Enthalpic. These fields determine a factor between 0 and 1 that multiplies the opening factor of each window and door in the zone according to the control action shown in Figure 15 for Ventilation Control Mode = Temperature and in Figure 16 for Ventilation Control Mode = Enthalpic. Modulation of the openings can reduce the large temperature swings that can occur if the windows/doors are open too far when they are venting, especially when there is a large inside-outside temperature difference.

The modulation takes the following form when Ventilation Control Mode = Temperature:

> T_{zone} - T_{out} □ [Lower Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor] ➔ Multiplication factor = 1.0
>
> [Lower Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor] < T_{zone} - T_{out} < [Upper Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor] ➔ Multiplication factor varies linearly from 1.0 to [Limit Value on Multiplier for Modulating Venting Open Factor]
>
> T_{zone} - T_{out} □ [Upper Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor] ➔ Multiplication factor = [Limit Value on Multiplier for Modulating Venting Open Factor]

One way of “tuning” the following modulation control parameters is to perform a sensitivity analysis for winter and/or summer design days to determine what combination of values causes the biggest reduction in zone air temperature fluctuations due to venting.

Note that the default values for the following fields are such that, if none of the fields are specified, the default values are assigned.

Field: Limit Value on Multiplier for Modulating Venting Open Factor

See Figure 15 or Figure 16. This field applies only if Ventilation Control Mode = Temperature or Enthalpic. This value may be from zero to 1.0, with the default being 0.0.

Field: Lower Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor

See Figure 15. This field applies only if Ventilation Control Mode = Temperature. This value may be from zero to less than 100˚C, with the default being 0˚C. The value for this field must be less than the value specified for the next field (Upper Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor).

Field: Upper Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor

See Figure 15. This field applies only if Ventilation Control Mode = Temperature. This value must be greater than 0˚C, with the default being 100˚C. The value for this field must be greater than the value specified for the previous field (Lower Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor).

Field: Lower Value on Inside/Outside Enthalpy Difference for Modulating the Venting Open Factor

See Figure 16. This field applies only if Ventilation Control Mode = Enthalpic. This value may be from zero to less than 300,000 J/kg, with the default being 0 J/kg. The value for this field must be less than the value specified for the next field (Upper Value on Inside/Outside Enthalpy Difference for Modulating the Venting Open Factor).

Field: Upper Value on Inside/Outside Enthalpy Difference for Modulating the Venting Open Factor

See Figure 16. This field applies only if Ventilation Control Mode = Enthalpic. This value must be greater than zero, with the default being 300,000 J/kg. The value for this field must be greater than the value specified for the previous field (Lower Value on Inside/Outside Enthalpy Difference for Modulating the Venting Open Factor).

Field: Venting Availability Schedule Name

The name of a schedule that specifies when venting is available. A zero or negative schedule value means venting is not allowed. A value greater than zero means venting can occur if other venting control conditions (specified by Ventilation Control Mode and Vent Temperature Schedule Name) are satisfied. This schedule name should not be confused with Vent Temperature Schedule Name.

If a Venting Availability Schedule Name is not specified, it is assumed that venting is always available.

Using Venting Availability Schedule allows you to turn off venting at certain times of the day (at night, for example), of the week (on weekends, for example), or of the year (during the winter, for example).

If used with Ventilation Control Mode = Constant, the ventilation rate is constant only when this schedule allows venting; otherwise the ventilation rate is set to zero.

If Ventilation Control Mode = NoVent, this schedule has no effect.

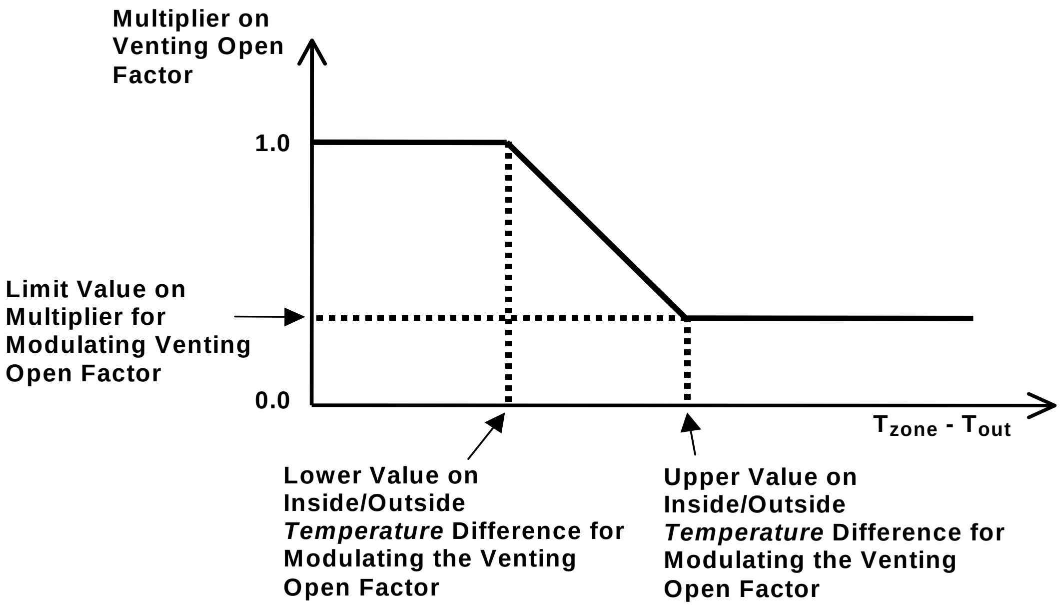


Figure 15. Modulation of venting area according to inside-outside temperature difference.

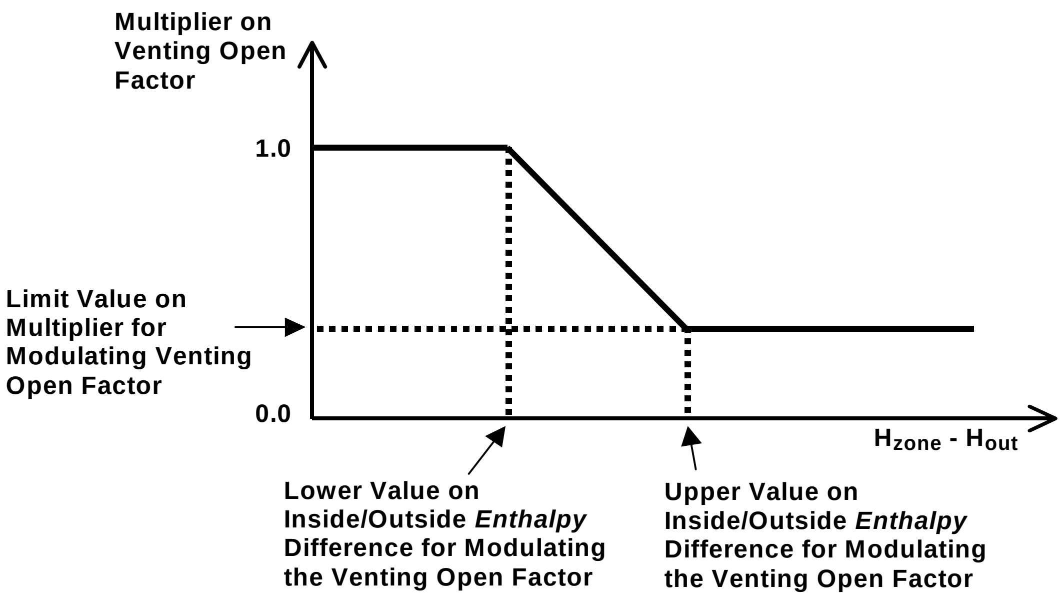


Figure 16. Modulation of venting area according to inside-outside enthalpy difference.

> Note: In order to establish an airflow network, each AirflowNetwork:Multizone:Zone object must have at least two surfaces defined with AirflowNetwork:Multizone:Surface objects, so that air can flow from one zone into other zones (or to outdoors) through the network (air mass flow conserved). In addition, for all AirflowNetwork:Multizone:Surface objects facing the same InsideFaceEnvironment (ref. Surface:HeatTransfer), at least two different environments must be defined for the other side of these surfaces (e.g., an external node and an adjacent zone, two adjacent zones, or two external nodes).

Below is the input data dictionary description for the AirflowNetwork:Multizone:Zone object.

```
AIRFLOWNETWORK:MULTIZONE:ZONE,
      \min-fields 8
      \memo This object is used to simultaneously control a thermal zone's window and door
      \memo openings, both exterior and interior.
  A1, \field Name of Associated Thermal Zone
      \required-field
      \type object-list
      \object-list ZoneNames
      \note Enter the zone name where ventilation control is required.
  A2, \field Ventilation Control Mode
      \type choice
      \key TEMPERATURE
      \key ENTHALPIC
      \key CONSTANT,
      \key NOVENT
      \default NOVENT
      \note When Ventilation Control Mode = TEMPERATURE or ENTHALPIC, the following
      \note fields are used to modulate the Ventilation Open Factor for all
      \note window and door openings in the zone according to the zone's
      \note inside-outside temperature or enthalpy difference.
      \note CONSTANT: controlled by field Venting Schedule.
      \note NOVENT: control will not open window or door during simulation (Ventilation
      \note Open Factor = 0).
  A3, \field Vent Temperature Schedule Name
      \type object-list
      \object-list ScheduleNames
      \note Used only if Ventilation Control Mode = TEMPERATURE or ENTHALPIC.
  N1, \field Limit Value on Multiplier for Modulating Venting Open Factor
      \type real
      \units dimensionless
      \minimum 0.0
      \maximum 1.0
      \default 0.0
      \note Used only if Ventilation Control Mode = TEMPERATURE or ENTHALPIC.
  N2, \field Lower Value on Inside/Outside Temperature Difference for Modulating the Venting Open
     Factor
      \type real
      \units deltaC
      \minimum 0.0
      \maximum< 100.0
      \default 0.0
      \note Applicable only if Ventilation Control Mode = TEMPERATURE.
      \note This value must be less than the corresponding upper value (next field).
  N3, \field Upper Value on Inside/Outside Temperature Difference for Modulating the Venting Open
     Factor
      \type real
      \units deltaC
      \minimum> 0.0
      \default 100.0
      \note Applicable only if Ventilation Control Mode = TEMPERATURE.
      \note This value must be greater than the corresponding lower value (previous field).
  N4, \field Lower Value on Inside/Outside Enthalpy Difference for Modulating the Venting Open
     Factor
      \type real
      \units J/kg
      \minimum 0.0
      \maximum< 300000.0
      \default 0.0
      \note Applicable only if Ventilation Control Mode = ENTHALPIC.
      \note This value must be less than the corresponding upper value (next field).
  N5, \field Upper Value on Inside/Outside Enthalpy Difference for Modulating the Venting Open
     Factor
      \type real
      \units J/kg
      \minimum> 0.0
      \default 300000.0
      \note Applicable only if Ventilation Control Mode = ENTHALPIC.
      \note This value must be greater than the corresponding lower value (previous field).
  A4; \field Venting Availability Schedule Name
      \type object-list
      \object-list ScheduleNames
      \note Non-zero schedule value means venting is allowed if other venting control
      \note conditions are satisfied. A zero (or negative) schedule value means venting
      \note is not allowed under any circumstances.
      \note The schedule values should be greater than or equal to 0 and less than or equal to 1.
```

```
      \note If this schedule is not specified then venting is allowed if
      \note other venting control conditions are satisfied.
      \note Not used if Ventilation Control Mode = NOVENT.
```

An IDF example is shown below:

```
AIRFLOWNETWORK:MULTIZONE:ZONE,
    RESISTIVE ZONE,          !- Name of Associated Thermal Zone
    Temperature,             !- Ventilation Control Mode
    WindowVentSched,         !- Vent Temperature Schedule Name
    0.3,                     !- Limit Value on Multiplier for Modulating Venting Open Factor
                             !- {dimensionless}
    5.0,                     !- Lower Value on Inside/Outside Temperature Difference for
                             !- Modulating the Venting Open Factor {deltaC}
    10.0,                    !- Upper Value on Inside/Outside Temperature Difference for
                             !- Modulating the Venting Open Factor {deltaC}
    0.0,                     !- Lower Value on Inside/Outside Enthalpy Difference for Modulating
                             !- the Venting Open Factor {J/kg}
    300000.0,                !- Upper Value on Inside/Outside Enthalpy Difference for Modulating
                             !- the Venting Open Factor {J/kg}
    VentingSched;            !- Venting Availability Schedule Name
```

AirflowNetwork:Multizone:Surface

The AirflowNetwork:Multizone:Surface object specifies the properties of a surface "linkage" through which air flows. This linkage is always associated with a heat transfer surface (wall, roof, floor, or a ceiling) or subsurface (door, glass door, or window) with both faces exposed to air. The linkage specifies two connected nodes: two zone nodes defined in AirflowNetwork: Multizone:Zone objects based on inside and outside face environment for an interior surface, or a zone node defined in an AirflowNetwork:Multizone:Zone object based on inside face environment and an external node defined in an AirflowNetwork: Multizone:External Node object for an exterior surface. The associated leakage component for this surface can be a crack (or surface effective leakage area) in an exterior or interior heat transfer surface or subsurface, or an exterior or interior window, door or glass door (heat transfer subsurface) that can be opened to allow air flow. The allowed surface air leakage components are:

- AirflowNetwork:Multizone:Surface Crack Data
- AirflowNetwork:Multizone:Surface Effective Leakage Area
- AirflowNetwork:Multizone:Component Detailed Opening
- AirflowNetwork:Multizone:Component Simple Opening

The last two components are used to modulate openness based on required conditions.

The AirflowNetwork:Multizone:Surface object allows a heat transfer surface or subsurface to have one crack (or one surface effective leakage area object), or a subsurface (i.e., window, door or glass door) to have one opening (detailed or simple).

An interior heat transfer surface (Surface:HeatTransfer) whose surface name is used as the input for the Outside Face Environment Object field represents a floor without ground contact and is not allowed as an AirflowNetwork:Multizone:Surface. A heat transfer surface defined in the Surface:HeatTransfer:ExteriorNaturalVentedCavity is also not allowed.

Field: Name of Associated Heat Transfer Surface

This is the name of the corresponding heat transfer surface or subsurface (wall, roof, ceiling, floor, window, door or glass door).

Information on this heat transfer surface is used by the program as follows:

(1) For a linkage associated with an exterior heat transfer surface: air flow through this linkage is between the outside environment and the thermal zone to which the surface belongs.

(2) For a linkage associated with an interior (i.e., interzone) heat transfer surface: air flow through this linkage is between the thermal zones separated by the surface (i.e., the thermal zone associated with the inside face environment and the thermal zone associated with the outside face environment).

(3) This heat transfer surface determines the height of the linkage, which is used in calculating buoyancy-related flow through the linkage.

Note: An interzone surface is defined twice in EnergyPlus, once in each of the zones that the surface separates. Therefore, an interzone surface has two names. Either of these names can be used in the AirflowNetwork:Multizone:Surface object for "Name of Associated Heat Transfer Surface." Do not enter two AirflowNetwork:Multizone:Surface objects corresponding to the two names. This would cause the air flow through the surface to be counted twice.

Field: Leakage Component Name

The name of the AirflowNetwork:Multizone:Surface Crack Data, AirflowNetwork:Multizone:Surface Effective Leakage Area, AirflowNetwork:Multizone:Component Simple Opening or AirflowNetwork:Multizone:Component Detailed Opening object associated with this air flow linkage.

If the name of an AirflowNetwork:Multizone:Component Detailed Opening or AirflowNetwork:Multizone:Component Simple Opening is given here, then the Name of Associated Heat Transfer Surface in the previous field must be that of a window, door or glass door heat transfer subsurface. Otherwise an error message will be reported.

If the name of an AirflowNetwork:Multizone:Surface Crack Data object or AirflowNetwork:Multizone:Surface Effective Leakage Area object is given here, the program will position the crack at the average height of the associated heat transfer surface or subsurface. The user can define multiple heat transfer surfaces (e.g., split a wall into several surfaces) to be more precise in establishing the crack location. Similarly, the user can define multiple heat transfer surfaces if a wall, for example, has multiple cracks or openings that need to be defined individually.

Field: External Node Name

The name of the associated AirflowNetwork:Multizone:External Node object, which determines the wind pressure coefficients for the heat transfer surface. Used only if Name of Associated Heat Transfer Surface is for an exterior surface.

If Wind Pressure Coefficient Type = SURFACE-AVERAGE CALCULATION in the AirflowNetwork Simulation object, this field is not used and a blank may be entered. If the surface is an interior (i.e., interzone) surface, leave this field blank.

Field: Window/Door Opening Factor, or Crack Factor

If this linkage is associated with an AirflowNetwork:Multizone:Component Detailed Opening or AirflowNetwork:Multizone:Component Simple Opening object (which means it is an openable window or door), then this field is called "Window/Door Opening Factor" and represents the value of the Opening Factor that is in effect when the Vent Temperature Schedule (defined in the AirflowNetwork:Multizone:Zone object) indicates that this window or door is open.

The AirflowNetwork model uses a combination of factors to determine the actual opening area for a window or door when it is venting. For example, consider a window that is 1.5m high and 2.0m wide (excluding frame). Assume that the AirflowNetwork:Multizone:Component Detailed Opening for this window has Type of Large Vertical Opening = 1 (non-pivoting window), Height Factor = 0.5 and Width Factor = 0.8. Then when the window is <u>fully open</u>, the opening area = height of opening (0.5x1.5) times width of opening (0.8x2.0) = 0.75x1.6 = 1.2 m^2. If the Window/Door Opening Factor is 0.75, then the opening area = 0.75x1.2 = 0.9 m^2.

If, in addition, the window is in a thermal zone for which opening modulation has been specified (ref: AirflowNetwork:Multizone:Zone) and the multiplication factor due to modulation is 0.3 in a particular time step, then the actual opening factor that time step = 0.3x0.75 = 0.225 and the actual opening area that time step = 0.3x0.9 = 0.27 m^2.

If this linkage is associated with an AirflowNetwork:Multizone:Surface Crack Data object, the following crack air flow equation is used.

$$Q = (\text{Crack Factor})*C_T*C_Q\left(\Delta P\right)^n$$

where

Q = air mass flow (kg/s)

C_Q = air mass flow coefficient (kg/s @ 1 Pa)

C_T = reference condition temperature correction factor (dimensionless). See AirflowNetwork:Multizone:Surface Crack Data.

ΔP = pressure difference across crack (Pa)

n = air flow exponent (dimensionless)

The following fields control venting. They are used only when Name of Associated Heat Transfer Surface is that of an openable exterior or interior window, door or glass door. They only apply to openings, and do not apply to surface cracks or effective leakage area. <u>If none of these fields is specified, or if Ventilation Control Mode = ZoneLevel, venting is controlled by the AirflowNetwork:Multizone:Zone object for the thermal zone containing the window or door (ref: AirflowNetwork:Multizone:Zone Data).</u>

Field: Ventilation Control Mode

Specifies the type of surface-level natural ventilation control.

Let T_{out} equal the outside air temperature, T_{zone} equal the previous time step's zone air temperature, T_{set} equal the Vent Temperature Schedule value, H_{zone} equal the specific enthalpy of zone air from the previous time step, and H_{out} equal the specific enthalpy of outside air. Then the four allowed choices for Ventilation Control Mode are:

NoVent: The openable window or door associated with this surface is <u>closed at all times</u> independent of indoor or outdoor conditions. The Venting Availability Schedule is ignored in this case.

Temperature: The openable window or door associated with this surface is opened if T_{zone} > T_{out} <u>**and**</u> T_{zone} > T_{set} <u>**and**</u> Venting Availability Schedule (see below) allows venting.

Enthalpic: The openable window or door associated with this surface is opened if H_{zone} > H_{out} <u>**and**</u> T_{zone} > T_{set} <u>**and**</u> Venting Availability Schedule allows venting.

Constant: Whenever this object's Venting Availability Schedule allows venting, the openable window or door associated with this surface is open, independent of indoor or outdoor conditions. Note that "Constant" here means that the size of this opening is fixed while venting; the air flow through this opening can, of course, vary from timestep to timestep.

ZoneLevel: Venting of the window or door is not controlled individually, but is controlled instead at the zone level. This means that the venting is determined by the AirflowNetwork:Multizone:Zone object for the thermal zone containing the window or door (ref: AirflowNetwork:Multizone:Zone object). This is the default value for this field.

Adjacent Temperature: This choice is used for an interior surface only. The openable interior window or door associated with this surface is opened if T_{zone} > $T_{adjacent\ zone}$ <u>**and**</u> T_{zone} > T_{set} <u>**and**</u> Venting Availability Schedule (see below) allows venting, where $T_{adjacent\ zone}$ is the adjacent zone temperature.

Adjacent Enthalpic: This choice is also used for an interior surface only. The interior openable window or door associated with this surface is opened if H_{zone} > $H_{adjacent\ zone}$ <u>**and**</u> T_{zone} > T_{set} <u>**and**</u> Venting Availability Schedule allows venting, where $H_{adjacent\ zone}$ is the adjacent zone specific enthalpy.

Field: Vent Temperature Schedule Name

The name of a schedule of zone air temperature set points that controls the opening of a window or door associated with this surface to provide natural ventilation. This setpoint is the temperature above which this openable window or door will be opened if the conditions described in the previous field Ventilation Control Mode are met.

The Vent Temperature Schedule applies only to a window or door attached to this surface that is specified using AirflowNetwork:Multizone:Component Detailed Opening or AirflowNetwork:Multizone:Component Simple Opening.

(The discussion under the field Window/Door Opening Factor in this object describes how the actual opening area of a window or door in a particular time step is determined.)

Modulation of Openings

The following five fields can be used to modulate this window/door opening when Ventilation Control Mode = Temperature or Enthalpic. These fields determine a factor between 0 and 1 that multiplies the opening factor of this window or door according to the control action shown in Figure 15 for Ventilation Control Mode = Temperature and in Figure 16 for Ventilation Control Mode = Enthalpic. Modulation of this opening can reduce the large temperature swings that can occur if the window/door is open too far when it is venting, especially when there is a large inside-outside temperature difference.

The modulation takes the following form when Ventilation Control Mode = Temperature:

> T_{zone} - T_{out} □ [Lower Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor] ➔ Multiplication factor = 1.0
>
> [Lower Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor] < T_{zone} - T_{out} < [Upper Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor] ➔ Multiplication factor varies linearly from 1.0 to [Limit Value on Multiplier for Modulating Venting Open Factor]
>
> T_{zone} - T_{out} □ [Upper Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor] ➔ Multiplication factor = [Limit Value on Multiplier for Modulating Venting Open Factor]

One way of "tuning" the following modulation control parameters is to perform a sensitivity analysis for winter and/or summer design days to determine what combination of values causes the biggest reduction in zone air temperature fluctuations due to venting.

Note that the default values for the following fields are such that, if none of the fields are specified, modulation will not occur.

Field: Limit Value on Multiplier for Modulating Venting Open Factor

See Figure 15 or Figure 16. This field applies only if Ventilation Control Mode = Temperature or Enthalpic. This value may be from zero to 1.0, with the default being 0.0.

Field: Lower Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor

See Figure 15. This field applies only if Ventilation Control Mode = Temperature. This value may be from zero to less than 100˚C, with the default being 0˚C. The value for this field must be less than the value specified for the next field (Upper Value for Inside/Outside Temperature Difference for Modulating the Venting Open Factor).

Field: Upper Value on Inside/Outside Temperature Difference for Modulating the Venting Open Factor

See Figure 15. This field applies only if Ventilation Control Mode = Temperature. This value must be greater than 0˚C, with the default being 100˚C. The value for this field must be greater than the value specified for the previous field (Lower Value for Inside/Outside Temperature Difference for Modulating the Venting Open Factor).

Field: Lower Value on Inside/Outside Enthalpy Difference for Modulating the Venting Open Factor

See Figure 16. This field applies only if Ventilation Control Mode = Enthalpic. This value may be from zero to less than 300,000 J/kg, with the default being 0 J/kg. The value for this field must be less than the value specified for the next field (Upper Value for Inside/Outside Enthalpy Difference for Modulating the Venting Open Factor).

Field: Upper Value on Inside/Outside Enthalpy Difference for Modulating the Venting Open Factor

See Figure 16. This field applies only if Ventilation Control Mode = Enthalpic. This value must be greater than zero, with the default being 300,000 J/kg. The value for this field must be greater than the value specified for the previous field (Lower Value for Inside/Outside Enthalpy Difference for Modulating the Venting Open Factor).

Field: Venting Availability Schedule Name

The name of a schedule that specifies when venting is available. A zero or negative schedule value means venting is not allowed. A value greater than zero means venting can occur if other venting control conditions (specified by Ventilation Control Mode and Vent Temperature Schedule Name) are satisfied. This schedule name should not be confused with Vent Temperature Schedule Name.

If a Venting Availability Schedule Name is not specified, it is assumed that venting is always available.

Using Venting Availability Schedule allows you to turn off venting at certain times of the day (at night, for example), week (on weekends, for example), or year (during the winter, for example).

If used with Ventilation Control Mode = Constant, the ventilation rate is constant only when this schedule allows venting; otherwise the ventilation rate is set to zero.

If Ventilation Control Mode = NoVent, this schedule has no effect.

> Note: In order to establish an airflow network, each AirflowNetwork:Multizone:Zone object must have at least two surfaces defined with AirflowNetwork:Multizone:Surface objects, so that air can flow from one zone into other zones (or to outdoors) through the network (air mass flow conserved). In addition, for all AirflowNetwork:Multizone:Surface objects facing the same InsideFaceEnvironment (ref. Surface:HeatTransfer), at least two different environments must be defined for the other side of these surfaces (e.g., an external node and an adjacent zone, two adjacent zones, or two external nodes).

Below is the input data dictionary description for the AirflowNetwork:Multizone: Surface object.

```
AIRFLOWNETWORK:MULTIZONE:SURFACE,
      \min-fields 4
      \memo This object specifies the properties of a surface linkage through which air flows.
  A1, \field Name of Associated Heat Transfer Surface
      \required-field
      \type object-list
      \object-list SurfAndSubSurfNames
      \note Enter the name of a heat transfer surface.
  A2, \field Leakage Component Name
      \required-field
      \type object-list
      \object-list SurfaceAirflowLeakageNames
      \note Enter the name of an air flow network leakage component. A leakage component is
      \note one of the following AIRFLOWNETWORK:MULTIZONE objects: COMPONENT DETAILED OPENING,
      \note COMPONENT SIMPLE OPENING, SURFACE CRACK DATA, or SURFACE EFFECTIVE LEAKAGE AREA.
  A3, \field External Node Name
      \type object-list
      \object-list ExternalNodeNames
      \note Used if Wind Pressure Coefficient Type = INPUT in the AIRFLOWNETWORK SIMULATION
      \note object, otherwise this field may be left blank.
  N1, \field Window/Door Opening Factor, or Crack Factor
      \required-field
      \type real
      \units dimensionless
      \note This field specifies a multiplier for a crack, window, or door.
  A4, \field Ventilation Control Mode
      \type choice
      \key TEMPERATURE
      \key ENTHALPIC
      \key CONSTANT,
      \key NOVENT
      \key ZONELEVEL
      \key ADJACENT TEMPERATURE
      \key ADJACENT ENTHALPIC
      \default ZONELEVEL
      \note When Ventilation Control Mode = TEMPERATURE or ENTHALPIC, the following
      \note fields are used to modulate the Ventilation Open Factor for a
      \note window or door opening according to the parent zone's
      \note inside-outside temperature or enthalpy difference.
      \note When Ventilation Control Mode = ADJACENT TEMPERATURE or ADJACENT ENTHALPIC,
      \note the following
      \note fields are used to modulate the Ventilation Open Factor for
      \note an interior
      \note window or door opening according to temperature or enthalpy difference
      \note between the parent zone and the adjacent zone.
      \note CONSTANT: controlled by field Venting Schedule.
      \note NOVENT: control will not open window or door during simulation (Ventilation Open
      \note Factor = 0).
      \note ZONELEVEL: control will be controlled by AirflowNetwork:Multizone:Zone Ventilation
      \note Control Mode.
  A5, \field Vent Temperature Schedule Name
      \type object-list
      \object-list ScheduleNames
      \note Used only if Ventilation Control Mode = TEMPERATURE or ENTHALPIC.
  N2, \field Limit Value on Multiplier for Modulating Venting Open Factor
      \type real
      \units dimensionless
      \minimum 0.0
      \maximum 1.0
      \default 0.0
      \note Used only if Ventilation Control Mode = TEMPERATURE or ENTHALPIC.
  N3, \field Lower Value on Inside/Outside Temperature Difference for Modulating the Venting Open
     Factor
      \note Applicable only if Ventilation Control Mode = TEMPERATURE
      \type real
      \units deltaC
      \minimum 0.0
      \default 0.0
  N4, \field Upper Value on Inside/Outside Temperature Difference for Modulating the Venting Open
     Factor
      \type real
      \units deltaC
      \minimum> 0.0
      \default 100.0
      \note Applicable only if Ventilation Control Mode = TEMPERATURE.
```

```
      \note This value must be greater than the corresponding lower value (previous field).
  N5, \field Lower Value on Inside/Outside Enthalpy Difference for Modulating the Venting Open
     Factor
      \type real
      \units J/kg
      \minimum 0.0
      \maximum< 300000.0
      \default 0.0
      \note Applicable only if Ventilation Control Mode = ENTHALPIC.
      \note This value must be less than the corresponding upper value (next field).
  N6, \field Upper Value on Inside/Outside Enthalpy Difference for Modulating the Venting Open
     Factor
      \type real
      \units J/kg
      \minimum> 0.0
      \default 300000.0
      \note Applicable only if Ventilation Control Mode = ENTHALPIC.
      \note This value must be greater than the corresponding lower value (previous field).
  A6; \field Venting Availability Schedule Name
      \type object-list
      \object-list ScheduleNames
      \note Non-zero schedule value means venting is allowed if other venting control conditions
      \note are satisfied. A zero (or negative) schedule value means venting is not allowed
      \note under any circumstances. The schedule values should be greater than or equal to
      \note 0 and less than or equal to 1. If this schedule is not specified then venting is
      \note allowed if other venting control conditions are satisfied. this field is not used
      \note if Ventilation Control Mode = NOVENT or ZONELEVEL.
```

IDF examples are provided below:

```
AIRFLOWNETWORK:MULTIZONE:SURFACE,
    Zn001:Wall001,            !- Name of Associated Heat Transfer Surface
    CR-1,                     !- Leakage Component Name
    SFacade,                  !- External Node Name
    1.0;                      !- Window/Door Opening Factor, or Crack Factor {dimensionless}

AIRFLOWNETWORK:MULTIZONE:SURFACE,
    Zn001:Wall001:Win001,     !- Name of Associated Heat Transfer Surface
    WiOpen1,                  !- Leakage Component Name
    SFacade,                  !- External Node Name
    0.5;                      !- Window/Door Opening Factor, or Crack Factor {dimensionless}

AIRFLOWNETWORK:MULTIZONE:SURFACE,
    Zn001:Wall001:Win002,     !- Name of Associated Heat Transfer Surface
    WiOpen2,                  !- Leakage Component Name
    WFacade,                  !- External Node Name
    0.5;                      !- Window/Door Opening Factor, or Crack Factor {dimensionless}
    Temperature,              !- Ventilation Control Mode
    WindowVentSched,          !- Vent Temperature Schedule Name
    0.3,                      !- Limit Value on Multiplier for Modulating Venting Open Factor
                              !- {dimensionless}
    5.0,                      !- Lower Value on Inside/Outside Temperature Difference for
                              !- Modulating the Venting Open Factor {deltaC}
    10.0,                     !- Upper Value on Inside/Outside Temperature Difference for
                              !- Modulating the Venting Open Factor {deltaC}
    0.0,                      !- Lower Value on Inside/Outside Enthalpy Difference for Modulating
                              !- the Venting Open Factor {J/kg}
    300000.0,                 !- Upper Value on Inside/Outside Enthalpy Difference for Modulating
                              !- the Venting Open Factor {J/kg}
    VentingSched;             !- Venting Availability Schedule Name
```

AirflowNetwork:Multizone:Surface Crack Data

This object specifies the properties of air flow through a crack and the associated measurement conditions. The following power law form is used that gives air flow through the crack as a function of the pressure difference across the crack:

$$Q = (\text{Crack Factor})*C_T*C_Q\left(\Delta P\right)^n$$

where

Q = air mass flow (kg/s)

C_Q = air mass flow coefficient (kg/s-Pa^n @ 1 Pa)

C_T = reference condition temperature correction factor (dimensionless)

ΔP = pressure difference across crack (Pa)

N = air flow exponent (dimensionless)

$$C_T = \left[\frac{\rho_o}{\rho}\right]^{n-1} \left[\frac{\nu_o}{\nu}\right]^{2n-1}$$

where

ρ = Air density at the specific air temperature and humidity ratio conditions [kg/m^3]

v = Air kinetic viscosity at the specific air temperature condition [m^2/s]

ρ_o = Air density at the reference air conditions provided by the object AirflowNetwork:Multizone:Reference Crack Conditions specified in the field Reference Crack Conditions [kg/m^3]

v_o = Air kinetic viscosity at the reference air temperature provided by the object AirflowNetwork:Multizone:Reference Crack Conditions specified in the field Reference Crack Conditions [m^2/s]

Note: The correction factor shown above is use for this particular component as specified.

Field: Name of Surface Crack Component

This is a name for this AirflowNetwork:Multizone:Surface Crack Data object. It is referenced by an AirflowNetwork:Multizone:Surface object.

Field: Air Mass Flow Coefficient at Reference Conditions

The value of the air mass flow coefficient, C_Q , in the crack air flow equation. It has units of kg/s at 1Pa. This value must be greater than zero.

Field: Air Mass Flow Exponent

The value of the exponent, n, in the crack air flow equation. The valid range is 0.5 to 1.0, with the default value being 0.65.

Field: Reference Crack Conditions

The name of the AirflowNetwork:Multizone:Reference Crack Conditions object which specifies the conditions under which the air mass flow coefficient was measured. If the user omits this field and no other reference crack conditions objects are defined in the input data file, then the default conditions for the AirflowNetwork:Multizone: Reference Crack Conditions object will be used. If the user omits this field and only one AirflowNetwork:Multizone:Reference Crack Conditions object is defined in the input data file, then those reference crack conditions will be used.

Below is the input data dictionary description for the AirflowNetwork:Multizone:Surface Crack Data object.

```
AIRFLOWNETWORK:MULTIZONE:SURFACE CRACK DATA,
      \min-fields 3
      \memo This object specifies the properties of air flow through a crack.
 A1 , \field Name of Surface Crack Component
      \required-field
      \type alpha
      \reference SurfaceAirflowLeakageNames
      \note Enter a unique name for this object.
 N1 , \field Air Mass Flow Coefficient at Reference Conditions
      \type real
      \required-field
      \units kg/s
      \minimum> 0
      \note Enter the air mass flow coefficient at the conditions defined
      \note in the Reference Crack Conditions object.
      \note Defined at 1 Pa pressure difference across this crack.
 N2 , \field Air Mass Flow Exponent
      \type real
      \units dimensionless
      \minimum 0.5
      \maximum 1.0
      \default 0.65
      \note Enter the air mass flow exponent for this surface crack.
 A2 ; \field Reference Crack Conditions
      \type object-list
      \object-list ReferenceCrackConditions
      \note Select a Reference Crack Conditions object name associated with
      \note the air mass flow coefficient entered above.
```

An IDF example is shown below:

```
AIRFLOWNETWORK:MULTIZONE:SURFACE CRACK DATA,
    CR-1,                     !- Name of Surface Crack Component
    0.01,                     !- Air Mass Flow Coefficient at Reference Conditions {kg/s}
    0.667,                    !- Air Mass Flow Exponent {dimensionless}
    ReferenceCrackConditions; !- Reference Crack Conditions
```

AirflowNetwork:Multizone:Reference Crack Conditions

This object specifies the reference conditions for temperature, humidity, and pressure which correspond to the AirflowNetwork:Multizone:Surface Crack Data object.

Field: Name of Reference Crack Conditions

The name of this Reference Crack Conditons object. This name is referenced by an AirflowNetwork:Multizone:Surface Crack Data object.

Field: Reference Temperature for Crack Data

The reference temperature in °C under which the Surface Crack Data were obtained. The default value is 20°C.

Field: Reference Barometric Pressure for Crack Data

The reference barometric pressure in Pa under which the Surface Crack Data were obtained. The default value is 101325 Pa.

Field: Reference Humidity Ratio for Crack Data

The reference humidity ratio in kg/kg under which the Surface Crack Data were obtained. The default value is 0 kg/kg.

Below is the input data dictionary description for the AirflowNetwork:Multizone: Reference Crack Conditions object.

```
AIRFLOWNETWORK:MULTIZONE:REFERENCE CRACK CONDITIONS,
      \min-fields 4
      \memo This object specifies the conditions under which the air mass flow coefficient was
      \memo measured.
 A1 , \field Name of Reference Crack Conditions
      \required-field
      \type alpha
      \reference ReferenceCrackConditions
      \note Enter a unique name for this object.
 N1 , \field Reference Temperature for Crack Data
      \type real
      \units C
      \default 20
      \note Enter the reference temperature under which the surface crack data were obtained.
 N2 , \field Reference Barometric Pressure for Crack Data
      \type real
      \units Pa
      \default 101325
      \minimum> 0
      \note Enter the reference barometric pressure under which the surface crack data
      \note were obtained.
 N3 ; \field Reference Humidity Ratio for Crack Data
      \type real
      \units kg/kg
      \default 0
      \note Enter the reference humidity ratio under which the surface crack data were obtained.
```

An IDF example is provided below:

```
AIRFLOWNETWORK:MULTIZONE:REFERENCE CRACK CONDITIONS,
    ReferenceCrackConditions,      !- Name of Reference Crack Conditions
    20.0,                          !- Reference Temperature for Crack Data {C}
    101325,                        !- Reference Barometric Pressure for Crack Data {Pa}
    0.0;                           !- Reference Humidity Ratio for Crack Data {kg/kg}
```

AirflowNetwork:Multizone:Surface Effective Leakage Area

The effective leakage area (ELA) object is used to define surface air leakage. It has five fields. The relationship between pressure and airflow may be expressed as:

$$\dot{m} = ELA * C_d \sqrt{2\rho} * \left(\Delta P_r\right)^{0.5-n} (\Delta P)^n$$

where

$\dot{m}$ = Air mass flow rate [kg/s]

ELA = Effective leakage area [m^2]

ρ = Air density [kg/m^3]

ΔP_r = Reference pressure difference [Pa]

ΔP = Pressure difference across this component [Pa]

C_d = Discharge coefficient [dimensionless]

n = Air mass flow exponent [dimensionless]

Field: Name of surface effective leakage area component

This is a name for this AirflowNetwork:Multizone:Surface Effective Leakage Area object. It is referenced by an AirflowNetwork:Multizone:Surface object.

Field: Effective leakage area

This numeric field is used to input the effective leakage area in square meters. The effective leakage area is used to characterize openings for infiltration calculations (ASHRAE Handbook of Fundamentals, 1997, pp 25.18). This value must be greater than zero.

Field: Discharge coefficient

This numeric field is used to input the discharge coefficient. This value must be greater than zero, with a default value of 1.0.

Field: Reference pressure difference

This numeric field is used to input the reference pressure difference [Pa]. This value must be greater than zero, with a default value of 4.0 Pa.

Field: Air mass flow exponent

This numeric field is used to input the pressure difference exponent. The valid range of the exponent is from 0.5 to 1.0, with a default value of 0.65.

> Note: There are two common sets of reference conditions: C_d = 1.0 and ΔP = 4 Pa, or C_d = 0.6 and ΔP = 10 Pa

Below is the input data dictionary description for the AirflowNetwork:Multizone: Surface Effective Leakage Area object.

```
AIRFLOWNETWORK:MULTIZONE:SURFACE EFFECTIVE LEAKAGE AREA,
      \min-fields 5
      \memo This object is used to define surface air leakage.
 A1 , \field Name of surface effective leakage area component
      \required-field
      \type alpha
      \reference SurfaceAirflowLeakageNames
      \note Enter a unique name for this object.
 N1 , \field Effective leakage area
      \required-field
      \type real
      \units m2
      \minimum> 0
      \note Enter the ratio of the leakage area to the area of the associated surface.
 N2 , \field Discharge coefficient
      \type real
      \units dimensionless
      \minimum> 0
      \default 1.0
      \note Enter the coefficient used in the air mass flow equation.
 N3 , \field Reference pressure difference
      \type real
      \units Pa
      \minimum> 0
      \default 4.0
      \note Enter the pressure difference used to define the air mass flow coefficient
      \note and exponent.
 N4 ; \field Air mass flow exponent
      \units dimensionless
      \type real
      \default .65
      \minimum 0.5
      \maximum 1.0
      \note Enter the exponent used in the air mass flow equation.
```

An IDF example is shown below:

```
AIRFLOWNETWORK:MULTIZONE:SURFACE EFFECTIVE LEAKAGE AREA,
    SurfaceELR,              !- Name of surface effective leakage area component
    0.07,                    !- Effective leakage area {m2}
    1.00,                    !- Discharge coefficient {dimensionless}
    4.0,                     !- Reference pressure difference {Pa}
    0.65;                    !- Air mass flow exponent {dimensionless}
```

AirflowNetwork:Multizone:Component Detailed Opening

This object specifies the properties of air flow through windows and doors (window, door and glass door heat transfer subsurfaces) when they are closed or open. The fields are similar to those for AirflowNetwork:Multizone: Surface Crack Data when the window or door is closed, but additional fields are required to describe the air flow characteristics when the window or door is open. These additional fields include opening type, opening dimensions, degree of opening, and opening schedule.

The AirflowNetwork model assumes that open windows or doors are vertical or close to vertical; for this reason they are called "Large Vertical Openings." Such openings can have air flow moving simultaneously in two different directions depending on stack effects and wind conditions (for example, flow from inside to outside at the top of a window and from outside to inside at the bottom). AirflowNetwork models such two-directional flow, but only for vertical openings.

It is assumed that the air flow through a window opening is unaffected by the presence of a shading device such as a shade or blind on the window. Also, the calculation of conductive heat transfer and solar gain through a window or door assumes that the window or door is closed.

The AirflowNetwork model does not have a model for bi-directional flow through large horizontal openings. For this reason, **AirflowNetwork:Multizone:Component Detailed Opening should not be used for horizontal openings**. The best modeling technique in this case is to put an AirflowNetwork:Multizone:Surface Crack Data object in a horizontal surface and use a large air mass flow coefficient. Crack flow is assumed to be uni-directional in any given time step (but can reverse flow direction from time step to time step).

A subsurface multiplier may be used to represent multiple subsurfaces and calculates total air flow when the subsurface (window, glassdoor, or door) is either closed or open. The total airflow across the surface is equal to the airflow based on the surface geometry multiplied by the subsurface multiplier.

Field: Detailed Opening Name

The name of this AirflowNetwork:Multizone:Component Detailed Opening object. It is referenced by an AirflowNetwork:Multizone:Surface object.

Field: Air Mass Flow Coefficient When Opening is Closed

Crack flow is assumed when the window or door is closed. The units for this air mass flow coefficient ($C_{Q,\, unit\ length}$) are different from the units for C_Q (kg/s at 1 Pa pressure difference) defined in an AirflowNetwork:Multizone:Surface Crack Data object. There is no default but the entered value must be greater than zero. The program will automatically generate four cracks around the perimeter of the window or door--one along the bottom, one along the top, and one on each side. The temperature correction factor used in the AirflowNetwork:Multizone:Surface Crack Data object is not used for this component to calculate air mass flow rate.

Field: Air Mass Flow Exponent When Opening Is Closed

Crack flow is assumed when the window or door is closed. In this case, the value of this field is the exponent, n, in the crack air flow equation. The valid range for this exponent is 0.5 to 1.0, with the default value being 0.65.

Field: Type of Large Vertical Opening (LVO)

This alpha field specifies the type of rectangular window or door. (Open windows or doors are also called Large Vertical Openings (LVOs). The choices for the opening type are Non-pivoted (LVO Type 1) and Horizontally-pivoted (LVO Type 2) with the default being Non-pivoted. The Non-pivoted type represents a regular window or door. The Horizontally-pivoted type represents a window with a horizontal axis ((i.e., a horizontally-pivoting window) and can not be used for a door.

Field: Extra Crack Length for LVO Type 1 With Multiple Openable Parts, or Height of Pivoting Axis for LVO Type 2

Specifies window or door characteristics that depend on the LVO type.

For LVO Type 1 (rectangular non-pivoted windows and doors) this field is the extra crack length in meters due to multiple openable parts, if present. "Extra" here means in addition to the length, calculated by the program, of the cracks on the top, bottom and sides of the window/door.

For LVO Type 2 (rectangular horizontally-pivoted windows) this field gives the height of the pivoting axis measured from the bottom of the glazed part of the window (m).

Field: Number of Sets of Opening Factor Data

This is the number of the following sets of data for opening factor, discharge coefficient, width factor, height factor, and start height factor. From two to four of these sets must be defined. The first set should be for Opening Factor = 0.0 and the last set should be for Opening Factor = 1.0. For example, if only two sets are defined, the first set should be for Opening Factor = 0.0 and the second set should be for Opening Factor = 1.0, as shown below in the IDF example below.

An "opening factor" refers to the amount that a window or door is opened. The program linearly interpolates each time step between the values of discharge coefficient, width factor, etc., in these sets using the opening factor for the window or door for the time step. (See discussion under the field Window/Door Opening Factor in the AirflowNetwork:Multizone:Zone object for a description of how the AirflowNetwork model determines the time-step value of the opening factor.)

Field Group: Opening Factor, Discharge Coefficient, Width Factor, Height Factor, Start Height Factor

Each field is described for as many groups as required in the previous field (number of sets of opening factor data). As the final field has specific requirements, this field (n) will be described.

Field: Opening Factor #1

The first opening factor of a window or door. This value must be 0.0. The default value is also 0.0.

For LVO Type 1 (rectangular non-pivoted window or door), the Opening Factor corresponds to the fraction of window or door that is opened.

For LVO Type 2 (rectangular horizontally-pivoted windows), the Opening Factor is determined by the window opening angle. For example, an opening angle of 45° corresponds to an Opening Factor of 0.50 since the maximum opening angle is 90°.

Field: Discharge Coefficient for Opening Factor #1

The discharge coefficient of the window or door for Opening Factor #1. The range is greater than 0.0 to less than or equal to 1.0. The default value is 0.001. The Discharge Coefficient indicates the fractional effectiveness for air flow through a window or door at that Opening Factor.

> Note: In the following, "window width" and "window height" are glazing dimensions; they do not include the frame, if present.

Field: Width Factor for Opening Factor #1

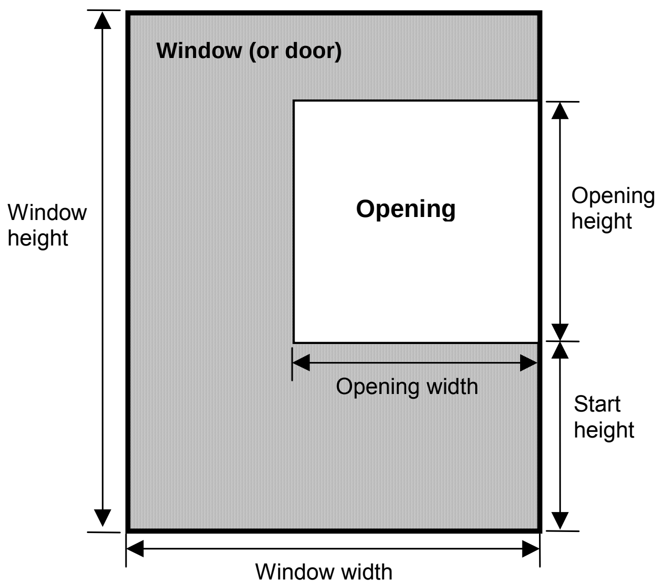
The Width Factor of the rectangular window or door for Opening Factor #1. The Width Factor is the opening width divided by the window or door width (see Figure 17). The range is 0.0 to 1.0. The default value is 0.0. Note that the width factor applies to rectangular windows or doors where the width is assumed constant along the entire height of the opening.

Field: Height Factor for Opening Factor #1

The Height Factor of the rectangular window or door for Opening Factor #1. The Height Factor is the opening height divided by the window or door height (see Figure 17). The range is 0.0 to 1.0. The default value is 0.0. Note that the height factor applies to rectangular windows or doors where the height is assumed constant along the entire width of the opening.

Field: Start Height Factor for Opening Factor #1

The Start Height Factor of the window or door for Opening Factor #1. The Start Height Factor is the Start Height divided by the window or door height (see Figure 17). The range is 0.0 to 1.0. The default is 0. Start Height is the distance between the bottom of the window or door and the bottom of the window or door opening. The sum of the Height Factor and the Start Height Factor must be less than 1.0 in order to have the opening within the window or door dimensions.



$$Width\ Factor = \frac{Opening\ Width}{Window\ Width}$$

$$Height\ Factor = \frac{Opening\ Height}{Window\ Height}$$

$$Start\ Height\ Factor = \frac{Start\ Height}{Window\ Height}$$

Figure 17. Window (or door) showing geometrical factors associated with an opening through which air flows.

Field: Opening Factor #n

When Number of Sets of Opening Factor Data = n, the value of Opening Factor #n must be set to 1.0.

Field: Discharge Coefficient for Opening Factor #n

The discharge coefficient of the window or door for Opening Factor #n. The range is greater than 0.0 to less than or equal to 1.0. The default value is 1.0.

Field: Width Factor for Opening Factor #2

The Width Factor of the rectangular window or door for Opening Factor #n. The Width Factor is the opening width divided by the window or door width (see Figure 17). The range is 0.0 to 1.0. The default value is 1.0.

Field: Height Factor for Opening Factor #2

The Height Factor of the rectangular window or door for Opening Factor #n. The Height Factor is the opening height divided by the window or door height (see Figure 17). The range is 0.0 to 1.0. The default value is 1.0.

Field: Start Height Factor for Opening Factor #2

The Start Height Factor of the window or door for Opening Factor #n. The Start Height Factor is the Start Height divided by the window or door height (see Figure 17). The range is 0.0 to 1.0. The default is 0.

When the opening factor value (as described under the field Window/Door Opening Factor in the AirflowNetwork:Multizone:Surface object) is between two Opening Factor field values, the values of Discharge Coefficient, Width Factor, Height Factor, and Start Height Factor are linearly interpolated.

Below is the input data dictionary description for the AirflowNetwork:Multizone: Component Detailed Opening object.

```
AIRFLOWNETWORK:MULTIZONE:COMPONENT DETAILED OPENING,
      \min-fields 16
      \memo This object specifies the properties of air flow through windows and doors (window,
      \memo door and glass door heat transfer subsurfaces) when they are closed or open.
 A1 , \field Detailed Opening Name
      \required-field
      \type alpha
      \reference SurfaceAirflowLeakageNames
      \note Enter a unique name for this object.
 N1 , \field Air Mass Flow Coefficient When Opening is Closed
      \required-field
      \type real
      \units kg/s-m
      \minimum> 0
      \note Defined at 1 Pa per meter of crack length. Enter the coefficient used in the
      \note following equation:
      \note Mass flow rate = Air Mass Flow Coefficient * (dP)^Air Mass Flow Exponent.
      \note Used only when opening (window or door) is closed.
 N2 , \field Air Mass Flow Exponent When Opening is Closed
      \units dimensionless
      \type real
      \minimum 0.5
      \maximum 1.0
      \default 0.65
      \note Enter the exponent used in the following equation:
      \note Mass flow rate = Air Mass Flow Coefficient * (dP)^Air Mass Flow Exponent.
      \note Used only when opening (window or door) is closed.
A2 ,  \field Type of Rectanguler Large Vertical Opening (LVO)
      \type choice
      \key Non-pivoted
      \key Horizontally pivoted
      \note Select the type of vertical opening: Non-pivoted opening or Horizontally-pivoted
      \note opening.
      \default Non-pivoted
 N3 , \field Extra crack length for LVO Non-pivoted type with multiple openable parts,
             or Height of pivoting axis for LVO Horizontally pivoted type
      \type real
      \units m
      \default 0
      \note Specifies window or door characteristics that depend on the LVO type.
      \note For the Non-pivoted Type (rectangular windows and doors), this field is the extra
      \note crack length in meters due to multiple openable parts, if present.
      \note Extra here means in addition to the length of the cracks on the top, bottom
      \note and sides of the window/door. For the Horizontally-pivoted Type, this field gives
      \note the height of the pivoting axis measured from the bottom of the glazed part
      \note of the window (m).
 N4 , \field Number of Sets of Opening Factor Data
      \required-field
      \type integer
      \minimum 2
      \maximum 4
      \note Enter the number of the following sets of data for opening factor,
      \note discharge coefficient, width factor, height factor, and start height factor.
 N5 , \field Opening factor #1
      \type real
      \units dimensionless
      \minimum 0
      \maximum 0
      \default 0
      \note This value must be specified as 0.
 N6 , \field Discharge coefficient for opening factor #1
      \type real
      \units dimensionless
      \minimum> 0
      \maximum 1
      \default 0.001
      \note The Discharge Coefficient indicates the fractional effectiveness
      \note for air flow through a window or door at that Opening Factor.
 N7 , \field Width factor for opening factor #1
      \type real
      \units dimensionless
      \minimum 0
      \maximum 1
      \default 0
      \note The Width Factor is the opening width divided by the window or door width.
```

```
N8 , \field Height factor for opening factor #1
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \default 0
     \note The Height Factor is the opening height divided by the window or door height.
N9 , \field Start height factor for opening factor #1
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \default 0
     \note The Start Height Factor is the Start Height divided by the window or door height.
     \note Start Height is the distance between the bottom of the window or door and the
     \note bottom of the window or door opening. The sum of the Height Factor and the Start
     \note Height Factor must be less than 1.0 in order to have the opening within the window
     \note or door dimensions.
N10, \field Opening factor #2
     \required-field
     \type real
     \units dimensionless
     \minimum> 0
     \maximum 1
     \note If Number of Sets of Opening Factor Data = 2, this value must be 1.0.
     \note If Number of Sets of Opening Factor Data = 3, this value must be less than 1.0.
     \note If Number of Sets of Opening Factor Data = 4, this value must be less than the
     \note value entered for Opening factor #3 and greater than the value entered
     \note for Opening factor #1.
N11, \field Discharge coefficient for Opening factor #2
     \type real
     \units dimensionless
     \minimum> 0
     \maximum 1
     \default 1
     \note The Discharge Coefficient indicates the fractional effectiveness
     \note for air flow through a window or door at that Opening Factor.
N12, \field Width factor for Opening factor #2
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \default 1
     \note The Width Factor is the opening width divided by the window or door width.
N13, \field Height factor for Opening factor #2
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \default 1
     \note The Height Factor is the opening height divided by the window or door height.
N14, \field Start height factor for Opening factor #2
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \default 1
     \note The Start Height Factor is the Start Height divided by the window or door height.
     \note Start Height is the distance between the bottom of the window or door and the
     \note bottom of the window or door opening. The sum of the Height Factor and the Start
     \note Height Factor must be less than 1.0 in order to have the opening within the window
     \note or door dimensions.
N15, \field Opening factor #3
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \note If Number of Sets of Opening Factor Data = 3, this value must be 1.0.
     \note If Number of Sets of Opening Factor Data = 4, this value must be less than 1.0,
     \note and greater than value entered for Opening factor #2.
N16, \field Discharge coefficient for Opening factor #3
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
```

```
     \default 0
     \note The Discharge Coefficient indicates the fractional effectiveness
     \note for air flow through a window or door at that Opening Factor.
N17, \field Width factor for Opening factor #3
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \default 0
     \note The Width Factor is the opening width divided by the window or door width.
N18, \field Height factor for Opening factor #3
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \default 0
     \note The Height Factor is the opening height divided by the window or door height.
N19, \field Start height factor for Opening factor #3
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \default 0
     \note The Start Height Factor is the Start Height divided by the window or door height.
     \note Start Height is the distance between the bottom of the window or door and the
     \note bottom of the window or door opening. The sum of the Height Factor and the Start
     \note Height Factor must be less than 1.0 in order to have the opening within the window
     \note or door dimensions.
N20, \field Opening factor #4
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \note If Number of Sets of Opening Factor Data = 4, this value must be 1.0
N21, \field Discharge coefficient for Opening factor #4
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \default 0
     \note The Discharge Coefficient indicates the fractional effectiveness
     \note for air flow through a window or door at that Opening Factor.
N22, \field Width factor for Opening factor #4
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \default 0
     \note The Width Factor is the opening width divided by the window or door width.
N23, \field Height factor for Opening factor #4
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \default 0
     \note The Height Factor is the opening height divided by the window or door height.
N24; \field Start height factor for Opening factor #4
     \type real
     \units dimensionless
     \minimum 0
     \maximum 1
     \default 0
     \note The Start Height Factor is the Start Height divided by the window or door height.
     \note Start Height is the distance between the bottom of the window or door and the
     \note bottom of the window or door opening. The sum of the Height Factor and the Start
     \note Height Factor must be less than 1.0 in order to have the opening within the window
     \note or door dimensions.
```

An IDF example is shown below:

```
AIRFLOWNETWORK:MULTIZONE:COMPONENT DETAILED OPENING,
    WiOpen1,                 !- Detailed Opening Name
    0.001,                   !- Air Mass Flow Coefficient When Opening is Closed {kg/s-m}
    0.667,                   !- Air Mass Flow Exponent When Opening is Closed {dimensionless}
    Non-pivoted,             !- Type of Large Vertical Opening (LVO)
    0.0,                     !- Extra crack length for LVO type 1 with multiple openable parts,
                             !- or Height of pivoting axis for LVO type 2 {m}
    2,                       !- Number of Sets of Opening Factor Data
    0.0,                     !- Opening factor #1 {dimensionless}
    0.5,                     !- Discharge coefficient for opening factor #1 {dimensionless}
    0.0,                     !- Width factor for opening factor #1 {dimensionless}
    1.0,                     !- Height factor for opening factor #1 {dimensionless}
    0.0,                     !- Start height factor for opening factor #1 {dimensionless}
    1.0,                     !- Opening factor #2 {dimensionless}
    0.6,                     !- Discharge coefficient for Opening factor #2 {dimensionless}
    1.0,                     !- Width factor for Opening factor #2 {dimensionless}
    1.0,                     !- Height factor for Opening factor #2 {dimensionless}
    0.0,                     !- Start height factor for Opening factor #2 {dimensionless}
    0,                       !- Opening factor #3 {dimensionless}
    0,                       !- Discharge coefficient for Opening factor #3 {dimensionless}
    0,                       !- Width factor for Opening factor #3 {dimensionless}
    0,                       !- Height factor for Opening factor #3 {dimensionless}
    0,                       !- Start height factor for Opening factor #3 {dimensionless}
    0,                       !- Opening factor #4 {dimensionless}
    0,                       !- Discharge coefficient for Opening factor #4 {dimensionless}
    0,                       !- Width factor for Opening factor #4 {dimensionless}
    0,                       !- Height factor for Opening factor #4 {dimensionless}
    0;                       !- Start height factor for Opening factor #4 {dimensionless}
```

AirflowNetwork:Multizone:Component Simple Opening

This object specifies the properties of air flow through windows, doors and glass doors (heat transfer subsurfaces) when they are closed or open. The AirflowNetwork model assumes that open windows or doors are vertical or close to vertical. The second and third fields are similar to those for AirflowNetwork:Multizone:Surface Crack Data, when the window or door is closed, but additional information is required to describe the air flow characteristics when the window or door is open. This additional information is specified in the last two fields. Compared to the object AirflowNetwork:Multizone:Component Detailed Opening, which requires more inputs at different opening factors, this object needs comparatively less inputs. For this reason it is called a simple opening. This opening also allows for the possibility of two-way flow due to temperature and resulting density differences. Therefore, it is possible to have a positive pressure difference at the top of the opening, and a negative pressure difference at the bottom (or vice versa) when the neutral height is between the bottom and top heights of the associated surface. This object's openness can also be modulated based on the same opening factor control as an AirflowNetwork:Multizone:Component Detailed Opening object. However, the opening factor is only applied to the subsurface width. The opening width is equal to opening factor multiplied by the subsurface width.

A subsurface multiplier may be used to represent multiple subsurfaces and calculates total air flow when the subsurface (window, glassdoor, or door) is either closed or open. The total airflow across the surface is equal to the airflow based on the surface geometry multiplied by the subsurface multiplier.

Field: Simple Opening Name

This is a name for this AirflowNetwork:Multizone:Compoenent Simple Opening object. It is referenced by an AirflowNetwork:Multizone:Surface object.

Field: Air Mass Flow Coefficient When Opening is Closed

The value of the air mass flow coefficient, $C_{Q,\,unit\ length}$, in the simple opening air flow equation. It has units of kg/s-m at 1Pa. The temperature correction factor is not applied for mass flow calculation.

Field: Air Mass Flow Exponent When Opening is Closed

The value of the exponent, n, in the crack air flow equation. The valid range is 0.5 to 1.0, with the default value being 0.65.

Field: Minimum density difference for two-way flow

This numeric field is used to input the minimum density difference above which two-way flow may occur due to stack effect. Density differences less than this value result in one-way flow. The minimum value for this field is greater than zero.

Field: Discharge Coefficient

This numeric field is used to input the discharge coefficient. This value must be greater than zero.

Below is the input data dictionary description for the AirflowNetwork:Multizone: Component Simple Opening object.

```
AIRFLOWNETWORK:MULTIZONE:COMPONENT SIMPLE OPENING,
      \min-fields 5
      \memo This object specifies the properties of air flow through windows and doors (window,
      \memo door and glass door heat transfer subsurfaces) when they are closed or open.
 A1 , \field Simple Opening Name
      \required-field
      \type alpha
      \reference SurfaceAirflowLeakageNames
      \note Enter a unique name for this object.
 N1 , \field Air Mass Flow Coefficient When Opening is Closed
      \required-field
      \type real
      \minimum> 0
      \units kg/s-m
      \note Defined at 1 Pa pressure difference. Enter the coefficient used in the following
      \note equation:
      \note Mass flow rate = Air Mass Flow Coefficient * (dP)^Air Mass Flow Exponent.
      \note Used only when opening (window or door) is closed.
 N2 , \field Air Mass Flow Exponent When Opening is Closed
      \units dimensionless
      \type real
      \default .65
      \minimum 0.5
      \maximum 1.0
      \note Enter the exponent used in the following equation:
      \note Mass flow rate = Air Mass Flow Coefficient * (dP)^Air Mass Flow Exponent.
      \note Used only when opening (window or door) is closed.
 N3 , \field Minimum density difference for two-way flow
      \required-field
      \units kg/m3
      \type real
      \minimum> 0
      \note Enter the minimum density difference above which two-way flow may occur due
      \note to stack effect.
 N4 ; \field Discharge coefficient
      \required-field
      \units dimensionless
      \type real
      \minimum> 0
      \note The Discharge Coefficient indicates the fractional effectiveness
      \note for air flow through a window or door at that Opening Factor.
```

An IDF example is provided below:

```
 AIRFLOWNETWORK:MULTIZONE:COMPONENT SIMPLE OPENING,
    WiOpen2,                 !- Simple Opening Name
    0.001,                   !- Air Mass Flow Coefficient When Opening Is Closed {kg/s-m}
    0.650,                   !- Air Mass Flow Exponent When Opening Is Closed {dimensionless}
    0.0001,                  !- Minimum density difference for two-way flow (kg/m3)
    1.0;                     !- Discharge coefficient (dimensionless)
```

AirflowNetwork:Multizone:Site Wind Conditions

The site wind conditions define the characteristics of the wind field near the building for a given wind direction. A different site wind condition can be defined for each wind direction.

Field: Wind Direction

The wind direction angle corresponding to the parameter specified in the following field. The wind direction is given by angle measured clockwise from geographic north and ranges from 0 to 360 degrees.

Field: Exponent of Wind Velocity Profile

This numeric field refers to the power law function used to derive the wind mean velocity profile. Reference values are 0.10 for a level surface with very small obstructions, 0.22 for rolling grassland broken by numerous obstructions such as trees or small houses, and 0.32 for a heterogeneous surface with structures taller than one story. The default value is 0.18

> Note: At least one of these objects is required. When one object is used, the program assumes the Wind Velocity Profile Exponent is independent of wind direction. When two or more objects are used, the exponent is linearly interpolated based on the given wind direction. If the given wind direction is larger than the largest value entered in a Wind Direction field, the exponent value will be linearly interpolated between the lowest and highest wind directions entered by the user.

Below is the input data dictionary description for the AirflowNetwork:Multizone:Site Wind Conditions object.

```
AIRFLOWNETWORK:MULTIZONE:SITE WIND CONDITIONS,
      \min-fields 2
      \memo This object defines the characteristics of the wind field near the building. More
      \memo than one site wind condition object may be used.
N1 ,  \field Wind Direction
      \required-field
      \type real
      \units deg
      \minimum 0.0
      \maximum 360.0
      \note Enter the wind direction angle corresponding to the environmental parameter in the
      \note following field.
N2 ;  \field Exponent of Wind Velocity Profile
      \type real
      \units dimensionless
      \default 0.18
      \minimum 0.0
      \maximum 0.5
      \note Enter the power law exponent used to derive the wind mean velocity profile.
```

IDF examples are provided below:

```
   AIRFLOWNETWORK:MULTIZONE:SITE WIND CONDITIONS,
    0.0,                    !- Wind Direction {deg}
    0.18,                   !- Exponent of Wind Velocity Profile {dimensionless}

   AIRFLOWNETWORK:MULTIZONE:SITE WIND CONDITIONS,
    180.0,                  !- Wind direction {deg}
    0.32,                   !- Exponent of Wind Velocity Profile {dimensionless}
```

AirflowNetwork:Multizone:External Node

External nodes in the AirflowNetwork model define environmental conditions outside of the building. These conditions include wind pressure coefficients that vary from façade to façade and can be highly dependent on the building geometry.

AirflowNetwork:MultiZone:External Node objects do **not** have to be entered if Wind Pressure Coefficient Type = SURFACE-AVERAGE CALCULATION in the AirflowNetwork Simulation object.

Field: Name of External Node

The external node name is associated with a particular building façade. This name is referenced by the External Node Name field of an AirflowNetwork:MultiZone:Wind Pressure Coefficient Values object (which gives wind pressure coefficients for the façade as a function of angle of wind incident on the façade) and by the External Node Name field of an AirflowNetwork:MultiZone:Surface object.

Field: External Node Height

Designates the reference height, in meters, used to calculate relative pressure. The default value is 0 meters.

Below is the input data dictionary description for the AirflowNetwork:Multizone: External Node object.

```
AIRFLOWNETWORK:MULTIZONE:EXTERNAL NODE,
      \min-fields 2
      \memo This object defines environmental conditions outside of the building.
 A1 , \field Name of External Node
      \required-field
      \type alpha
      \reference ExternalNodeNames
      \note Enter a unique name for this object.
      \note This node name will be referenced by a particular building facade.
 N1 ; \field External Node Height
      \required-field
      \type real
      \units m
      \default 0.0
      \note Designates the reference height used to calculate relative pressure.
```

IDF examples are provided below:

```
AIRFLOWNETWORK:MULTIZONE:EXTERNAL NODE,
    NFacade,                 !- Name of External Node
    1.524;                   !- External Node Height {m}

AIRFLOWNETWORK:MULTIZONE:EXTERNAL NODE,
    EFacade,                 !- Name of External Node
    1.524;                   !- External Node Height {m}

AIRFLOWNETWORK:MULTIZONE:EXTERNAL NODE,
    SFacade,                 !- Name of External Node
    1.524;                   !- External Node Height {m}

AIRFLOWNETWORK:MULTIZONE:EXTERNAL NODE,
    WFacade,                 !- Name of External Node
    1.524;                   !- External Node Height {m}

AIRFLOWNETWORK:MULTIZONE:EXTERNAL NODE,
    Horizontal,              !- Name of External Node
    3.028;                   !- External Node Height {m}
```

AirflowNetwork:Multizone:Wind Pressure Coefficient Array

The reference height and wind directions are first specified under the AirflowNetwork:MultiZone:Wind Pressure Coefficient Array object. The user may specify up to 36 different wind directions in ascending order. These are then referenced by AirflowNetwork:MultiZone:Wind Pressure Coefficient Values objects defined for each AirflowNetwork:MultiZone:External Node.

The AirflowNetwork:MultiZone:Wind Pressure Coefficient Array object is unique and needs to be entered only if Wind Pressure Coefficient Type = INPUT in the AirflowNetwork Simulation object. If Wind Pressure Coefficient Type = SURFACE-AVERAGE CALCULATION, this object is not required.

Field: WPC Array Name

The name of this AirflowNetwork:MultiZone:Wind Pressure Coefficient Array object. This name is referenced by each AirflowNetwork:MultiZone:Wind Pressure Coefficient Values object which, for each AirflowNetwork:MultiZone:External Node, gives the wind pressure coefficients at each of the wind directions listed in the AirflowNetwork:MultiZone:Wind Pressure Coefficient Array. This name is also referenced by the AirflowNetwork Simulation object, indicating that this AirflowNetwork:MultiZone:Wind Pressure Coefficient Array and the pressure coefficients in the associated AirflowNetwork:MultiZone:Wind Pressure Coefficient Values objects will be used in the air flow simulation.

Field: Reference Height for WPC data

The building reference height in meters assumed for the wind pressure coefficient (WPC) values given in the AirflowNetwork:MultiZone:Wind Pressure Coefficient Values object. The allowable range is 0+ to 1000m. The default value is 10 m.

The following fields specify the wind directions--**measured clockwise from North**--that correspond to the WPC values in the AirflowNetwork:MultiZone:Wind Pressure Coefficient Values objects. Wind directions are entered as integer degrees in ascending order between 0 and 360 degrees. The number of non-blank wind directions must match the number of wind pressure coefficient values in each of the AirflowNetwork:MultiZone:Wind Pressure Coefficient Values objects.

Field: Wind Direction #1-Wind Direction #N

Each field references the wind direction corresponding to the first through the Nth WPC value in each of the AirflowNetwork:MultiZone:Wind Pressure Coefficient Values objects. *N* can be as high as 36.

Below is the input data dictionary description for the AirflowNetwork:Multizone:Wind Pressure Coefficient Array object.

```
AIRFLOWNETWORK:MULTIZONE:WIND PRESSURE COEFFICIENT ARRAY,
      \min-fields 4
      \memo Used only if Wind Pressure Coefficient (WPC) Type = INPUT in the AirflowNetwork
      \memo Simulation object. Number of WPC Values in the corresponding
      \memo AIRFLOWNETWORK:MULTIZONE:WIND PRESSURE COEFFICIENT VALUES
      \memo object must be the same as the number of wind directions specified for this
      \memo AIRFLOWNETWORK:MULTIZONE:WIND PRESSURE COEFFICIENT ARRAY object.
 A1 , \field WPC Array Name
      \required-field
      \reference WPCSetNames
      \type alpha
      \note Enter a unique name for the object.
 N1 , \field Reference Height for WPC Data
      \required-field
      \type real
      \units m
      \minimum> 0
      \maximum 1000
      \note Enter the building reference height assumed in the
      \note AirFlowNetwork:Multizone:Wind Pressure Coefficient Values object.
 N2 , \field Wind Direction #1
      \required-field
      \type real
      \units deg
      \minimum 0.0
      \maximum 360.0
      \note Enter the wind direction corresponding to the 1st WPC Array value.
--reduced for brevity --
N37; \field Wind Direction #36
      \type real
      \units deg
      \minimum 0.0
      \maximum 360.0
      \note Enter the wind direction corresponding to the 36th WPC Array value.
```

An IDF example is provided below:

```
AIRFLOWNETWORK:MULTIZONE:WIND PRESSURE COEFFICIENT ARRAY,
    Every 30 Degrees,        !- WPC Array Name
    10.0,                    !- Reference Height for WPC Data {m}
    0,                       !- Wind Direction #1 {deg}
    30,                      !- Wind Direction #2 {deg}
    60,                      !- Wind Direction #3 {deg}
    90,                      !- Wind Direction #4 {deg}
    120,                     !- Wind Direction #5 {deg}
    150,                     !- Wind Direction #6 {deg}
    180,                     !- Wind Direction #7 {deg}
    210,                     !- Wind Direction #8 {deg}
    240,                     !- Wind Direction #9 {deg}
    270,                     !- Wind Direction #10 {deg}
    300,                     !- Wind Direction #11 {deg}
    330;                     !- Wind Direction #12 {deg}
```

AirflowNetwork:MultiZone:Wind Pressure Coefficient Values

This object specifies up to 36 wind pressure coefficients (WPCs) for an AirflowNetwork:MultiZone:External Node. These coefficients are defined for each of the wind directions defined in the unique AirflowNetwork:MultiZone:Wind Pressure Coefficient Array object. In the air flow calculation, interpolation of the specified WPC values is done for time-step values of wind direction.

AirflowNetwork:MultiZone:Wind Pressure Coefficient Values objects need to be entered only if the Wind Pressure Coefficient Type = INPUT in the AirflowNetwork Simulation object. If Wind Pressure Coefficient Type = SURFACE-AVERAGE CALCULATION, this object is not required.

Field: AirflowNetwork WPC Array Name

Name of the associated AirflowNetwork:MultiZone:Wind Pressure Coefficient Array, which lists the wind direction corresponding to each wind pressure coefficient value in this AirflowNetwork:MultiZone:Wind Pressure Coefficient Values object.

Field: External Node Name

The name of the AirflowNetwork:MultiZone:External Node that corresponds to the WPC values given in the following fields.

Field: WPC Value #1

The WPC (wind pressure coefficient) value for the building façade indicated by the External Node Name field above. This WPC value corresponds to the first wind direction in the AirflowNetwork:MultiZone:Wind Pressure Coefficient Array. Note that WPC values can be positive, negative or zero.

Field: WPC Value #2

The WPC (wind pressure coefficient) value for the building façade indicated by the External Node Name field above. This WPC value corresponds to the second wind direction in the AirflowNetwork:MultiZone:Wind Pressure Coefficient Array.

-- reduced for brevity --

Field: WPC Value #N

The WPC (wind pressure coefficient) value for the building façade indicated by the External Node Name field above. This WPC value corresponds to the *N*th wind direction in the AirflowNetwork:MultiZone:Wind Pressure Coefficient Array. *N* can be as high as 36.

Obtaining WPC values

WPC values can be obtained from wind tunnel measurements, CFD calculations, or from published values for different building shapes.

For **rectangular buildings** EnergyPlus will automatically calculate surface-averaged Cp values for the walls and roof of the building if you specify Wind Pressure Coefficient Type = SURFACE-AVERAGE CALCULATION in the AirflowNetwork Simulation object. In this case you do not have to enter any AirflowNetwork:MultiZone:Wind Pressure Coefficient Values objects.

Below is the input data dictionary description for the AirflowNetwork:Multizone:Wind Pressure Coefficient Values object.

```
AIRFLOWNETWORK:MULTIZONE:WIND PRESSURE COEFFICIENT VALUES,
      \min-fields 4
      \memo Used only if Wind Pressure Coefficient (WPC) Type = INPUT in the AirflowNetwork
      \memo Simulation object. The number of WPC numeric inputs must correspond to the number
      \memo of wind direction inputs in the AirflowNetwork:Multizone:Wind Pressure Coefficient
      \memo Array object.
 A1 , \field AirflowNetwork WPC Array Name
      \required-field
      \type object-list
      \object-list WPCSetNames
      \note Enter a unique name for this object.
 A2 , \field External Node Name
      \required-field
      \type object-list
      \object-list ExternalNodeNames
      \note Enter the name of the external node corresponding to this WPC Array.
 N1 , \field WPC Value #1
      \required-field
      \type real
      \units dimensionless
      \note Enter the WPC Value corresponding to the 1st wind direction.
 N2 , \field WPC Value #2
      \required-field
      \type real
      \units dimensionless
      \note Enter the WPC Value corresponding to the 2nd wind direction.
 --reduced for brevity --
 N36; \field WPC Value #36
      \type real
      \units dimensionless
      \note Enter the WPC Value corresponding to the 36th wind direction.
```

An IDF example is provided below:

```
AIRFLOWNETWORK:MULTIZONE:WIND PRESSURE COEFFICIENT VALUES,
    Every 30 Degrees,        !- AirflowNetwork WPC Array Name
    NFacade,                 !- External Node Name
    0.60,                    !- WPC Value #1 {dimensionless}
    0.48,                    !- WPC Value #2 {dimensionless}
    0.04,                    !- WPC Value #3 {dimensionless}
    -0.56,                   !- WPC Value #4 {dimensionless}
    -0.56,                   !- WPC Value #5 {dimensionless}
    -0.42,                   !- WPC Value #6 {dimensionless}
    -0.37,                   !- WPC Value #7 {dimensionless}
    -0.42,                   !- WPC Value #8 {dimensionless}
    -0.56,                   !- WPC Value #9 {dimensionless}
    -0.56,                   !- WPC Value #10 {dimensionless}
    0.04,                    !- WPC Value #11 {dimensionless}
    0.48;                    !- WPC Value #12 {dimensionless}
```

The previous sections of this AirflowNetwork model discussion describe input objects used for multizone airflow calculations. The next section presents the input object for distribution system nodes, which are used to perform distribution system simulations. Although thermal zones are required to perform distribution system simulations, the thermal zones are already defined in the multizone input section (described previously), so that there is no need to repeat the inputs for thermal zones when modeling an air distribution system. The same is also true for surface air leakage. This section has only one object: AirflowNetwork:Distribution:Node.

AirflowNetwork:Distribution:Node

The AirflowNetwork:Distribution:Node object is used to represent air distribution system nodes for the AirflowNetwork model. The EnergyPlus nodes defined in an Air Primary Loop are a subset of the nodes used to simulate the distribution system using the AirflowNetwork model. For example, the inlet node of a fan and the outlet node of a coil defined in an Air Primary Loop must be defined as nodes using the AirflowNetwork:Distribution:Node object. A set of EnergyPlus Zone Equipment nodes is also a subset of the AirflowNetwork:Distribution:Nodes. For example, zone inlet and outlet nodes must be defined as nodes using the AirflowNetwork:Distribution: Node object. In addition, although mixers and splitters are defined as objects with inlet and outlet nodes within EnergyPlus, the AirflowNetwork:Distribution:Node object treats mixers and splitters as single nodes. The node objects are referenced by AirflowNetwork:Distribution:Linkage objects.

In summary, all nodes used to define an Air Primary Loop (except splitters, mixers, and outside air systems which are treated as single nodes) and its connections to a thermal zone must be specified as AirflowNetwork:Distribution:Nodes. If distribution system air leaks are to be modeled, additional AirflowNetwork:Distribution:Nodes may be defined along with AirflowNetwork:Distribution:Components (e.g., leak or leak ratio) to define the air leakage characteristics.

> Note: Supply and return leaks are not allowed in an Air Primary Loop. They can only be modeled in the Zone Equipment Loop (i.e., return leaks may be modeled between the zone return node and the zone mixer inlet or the zone mixer outlet and the zone equipment loop outlet; and supply leaks may be modeled between the zone equipment loop inlet and the zone splitter inlet node or the zone splitter outlet node and the zone supply node).

Field: Name of Node

The name of an air distribution system node. This node name is referenced by an AirflowNetwork:Distribution:Linkage and in the output listing. Each node should have a unique name within the AirflowNetwork:Distribution:Node objects (however, the node name may be used elsewhere as regular EnergyPlus node names such as the fan inlet node or coil outlet node).

Field: Name of Associated EnergyPlus Node or Object

Designates node names defined in another EnergyPlus object, so that the AirflowNetwork:Distribution:Node object is able to get input parameters and node conditions from the associated EnergyPlus node or object. The actual node name is entered here and represents a node already defined in an air primary loop or zone equipment loop. This field is left blank if the EnergyPlus Node Type field below is entered as Mixer, Splitter, Outside Air System, or Other.

Field: EnergyPlus Object or Node Type

This choice field distinguishes the node type for the EnergyPlus node or object name defined above. Five node types are available:

- MIXER..Represents a mixer defined in EnergyPlus
- SPLITTER.. Represents a splitter defined in EnergyPlus
- OUTSIDE AIR SYSTEM..Represents an Outside Air System object used in EnergyPlus
- OA MIXER OUTSIDE AIR STREAM NODE NAME..Represents an external node name specified as an Outside_Air_Stream_Node in the Outside Air Mixer object when the OUTSIDE AIR SYSTEM is used.
- OTHER..Represents a type not already defined above

Field: Node Height

Designates the reference height in meters used to calculate relative pressure. The default value is 0 meters.

Below is the input data dictionary description for the AirflowNetwork:Distribution:Node object.

```
AIRFLOWNETWORK:DISTRIBUTION:NODE,
      \min-fields 4
      \memo This object represents an air distribution node in the AirFlowNetwork model.
 A1 , \field Name of Node
      \required-field
      \type alpha
      \reference AirflowNetwork NodeNames
      \note Enter a unique name for this object.
 A2 , \field Name of Associated EnergyPlus Node or Object
      \type alpha
      \note Designates node names defined in another object. The node name may occur in air
      \note branches. Enter a node name to represent a node already defined in an air loop.
      \note Leave this field blank if the EnergyPlus Node Type field below is entered as
      \note Mixer, Splitter, Outside Air System, or Other.
 A3 , \field EnergyPlus Object or Node Type
      \type choice
      \key MIXER
      \key SPLITTER
      \key OUTSIDE AIR SYSTEM
      \key OA MIXER OUTSIDE AIR STREAM NODE
      \key OTHER
      \note Designates node type for the EnergyPlus node or object name defined in the
      \note field above.
      \note MIXER -- Represents a mixer defined in EnergyPlus.
      \note SPLITTER -- Represents a splitter defined in EnergyPlus.
      \note OUTSIDE AIR SYSTEM -- Represents an Outside Air System object in EnergyPlus.
      \note OA MIXER OUTSIDE AIR STREAM NODE -- Represents an external node used in the
      \note Outside Air Mixer object in EnergyPlus.
      \note OTHER -- none of the above, the node name already defined in the previous field
      \note is part of an air loop.
 N1 ; \field Node Height
      \type real
      \units m
      \default 0.0
      \note Enter the reference height used to calculate the relative pressure.
```

IDF examples are provided below:

```
AIRFLOWNETWORK:DISTRIBUTION:NODE,
    EquipmentInletNode,      !- Name of Node
    Zone Equipment Inlet Node,  !- Name of Associated EnergyPlus Node or Object
    Other,                   !- EnergyPlus Object or Node Type
    3.0;                     !- Node Height {m}

AIRFLOWNETWORK:DISTRIBUTION:NODE,
    SupplyMainNode,          !- Name of Node
    ,                        !- Name of Associated EnergyPlus Node or Object
    Other,                   !- EnergyPlus Object or Node Type
    3.0;                     !- Node Height {m}

AIRFLOWNETWORK:DISTRIBUTION:NODE,
    MainSplitterNode,        !- Name of Node
    ,                        !- Name of Associated EnergyPlus Node or Object
    Splitter,                !- EnergyPlus Object or Node Type
    3.0;                     !- Node Height {m}
```

The next section describes AirflowNetwork Components, with the 7 available types listed below. All required fields for each component represent a relationship between pressure difference and airflow. The components are referenced in AirflowNetwork: Distribution:Linkage objects.

- AirflowNetwork:Distribution:Component Leak
- AirflowNetwork:Distribution:Component Leakage Ratio
- AirflowNetwork:Distribution:Component Duct
- AirflowNetwork:Distribution:Component Constant Volume Fan
- AirflowNetwork:Distribution:Component Coil
- AirflowNetwork:Distribution:Component Terminal Unit
- AirflowNetwork:Distribution:Component Constant Pressure Drop

AirflowNetwork:Distribution:Component Leak

This component may be also called a power law component and is used to represent a supply or return air leak in an air distribution system. Its relationship between pressure difference and airflow may be expressed as:

$$\dot{m} = C_T C \left(\Delta P \right)^n$$

where

$\dot{m}$ = Air mass flow rate through the component [kg/s]

C = Air mass flow coefficient (kg/s at 1 Pa pressure difference)

ΔP = Total pressure loss across the element [Pa]

n = Air mass flow exponent

C_T = Temperature correction factor

$$C_T = \left[\frac{\rho_o}{\rho} \right]^{n-1} \left[\frac{\nu_o}{\nu} \right]^{2n-1}$$

where

ρ = Air density at the specific air temperature and humidity ratio conditions [kg/m^3]

v = Air kinetic viscosity at the specific air temperature condition [m^2/s]

ρ_o = Air density at air conditions of 20°C, 0 kg/kg and 101325 Pa [kg/m^3]

v_o = Air kinetic viscosity at an air temperature of 20°C [m^2/s]

> Note: The correction factor shown above is use for this particular component as specified.

Field: Name of Supply or Return Leak

A unique name identifying a supply or return air leak in an air distribution system. This unique name will be referenced by an AirflowNetwork:Distribution:Linkage object to represent a component leak.

Field: Air Mass Flow Coefficient

This numeric field is defined as the air mass flow coefficient at 1 Pa pressure difference across this component. Valid entries must be greater than zero.

Field: Air Mass Flow Exponent

This numeric field is defined as the pressure difference exponent across the component. Valid entries are from 0.5 to 1.0, with the default value being 0.65.

Below is the input data dictionary description for the AirflowNetwork:Distribution: Component Leak object.

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT LEAK,
      \min-fields 3
      \memo This object defines the characteristics of a supply or return air leak.
 A1 , \field Name of Supply or Return Leak
      \required-field
      \type alpha
      \reference AirflowNetwork ComponentNames
      \note Enter a unique name for this object.
 N1 , \field Air Mass Flow Coefficient
      \required-field
      \type real
      \units kg/s
      \minimum> 0
      \note Defined at 1 Pa pressure difference across this component.
      \note Enter the coefficient used in the following equation:
      \note Mass flow rate = Air Mass Flow Coefficient * (dP)^Air Mass Flow Exponent
 N2 ; \field Air Mass Flow Exponent
      \type real
      \units dimensionless
      \minimum 0.5
      \maximum 1.0
      \default 0.65
      \note Enter the exponent used in the following equation:
      \note Mass flow rate = Air Mass Flow Coefficient * (dP)^Air Mass Flow Exponent
```

IDF examples are provided below:

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT LEAK,
    MainSupplyLeak,          !- Name of Supply or Return Leak
    0.0001,                  !- Air Mass Flow Coefficient {kg/s}
    0.65;                    !- Air Mass Flow Exponent {dimensionless}

AIRFLOWNETWORK:DISTRIBUTION:COMPONENT LEAK,
    ZoneSupplyLeak,          !- Name of Supply or Return Leak
    0.01,                    !- Air Mass Flow Coefficient {kg/s}
    0.65;                    !- Air Mass Flow Exponent {dimensionless}
```

AirflowNetwork:Distribution:Component Leakage Ratio

The leakage ratio component is generally used to define supply and return leaks with respect to a constant fan flow. This object requires 5 inputs. The relationship between pressure and airflow may be expressed as a power law element:

$$\dot{m} = C_{equ} \left(\Delta P \right)^n$$

where

ρ = Air density [kg/m^3]

ΔP = Total pressure loss across the element [Pa]

n = Air mass flow exponent

C_{equ} = Equivalent air mass flow coefficient

$$C_{equ} = r * Q_r * \rho * \left(\Delta P_r \right)^{-n}$$

where

r = Effective leakage ratio [dimensionless]

Q_r = Maximum airflow rate [m^3/s]

ΔP_r = Reference pressure difference [Pa]

n = Air mass flow exponent [dimensionless]

Field: Name of Effective Leakage Ratio

A unique name identifying a supply or return air leak (ratio with respect to the constant volume fan flow rate) in an air distribution system. This unique name will be referenced in an AirflowNetwork:Distribution:Linkage object to represent a component.

Field: Effective Leakage Ratio

This numeric field is used to input the effective leakage ratio. This value must be greater than zero and less than or equal to 1. The effective leakage ratio is used to characterize supply and return leaks with respect to the constant fan flow (supply or return air leak flow rate divided by the maximum air flow rate for the fan).

Field: Maximum Flow Rate

This numeric field is used to input the maximum flow rate for a constant volume fan [m^3/s]. This value must be greater than 0 m^3/s.

Field: Reference Pressure Difference

This numeric field is used to input the reference pressure difference [Pa]. This value must be greater than 0 Pa.

Field: Air Mass Flow Exponent

This numeric field is used to input the pressure difference exponent. The value of the exponent can be from 0.5 to 1.0, with the default value being 0.65.

> Note: The reference pressure difference is defined as the difference between pressures of originate and terminate nodes for supply and return leaks. In general, it may require that a simulation be performed with an initial guess for reference pressure difference using design day conditions. After obtaining pressures at the leakage nodes, more realistic reference pressure differences can be entered. It should be pointed out that since pressures at the nodes vary with temperature and other conditions, the effective leakage ratio is only an estimate. In other words, the exact leakage ratio may not be available.

Below is the input data dictionary description for the AirflowNetwork:Distribution: Component Leakage Ratio object.

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT LEAKAGE RATIO,
      \min-fields 5
      \memo This object is used to define supply and return air leaks with respect to the fan's
      \memo maximum air flow rate.
 A1 , \field Name of Effective Leakage Ratio
      \required-field
      \type alpha
      \reference AirflowNetwork ComponentNames
      \note Enter a unique name for this object.
 N1 , \field Effective Leakage Ratio
      \type real
      \units dimensionless
      \minimum> 0.0
      \maximum 1.0
      \note Defined as a ratio of leak flow rate to the maximum flow rate.
 N2 , \field Maximum Flow Rate
      \required-field
      \units m3/s
      \type real
      \minimum> 0.0
      \note Enter the maximum air flow rate in this air loop.
 N3 , \field Reference Pressure Difference
      \required-field
      \units Pa
      \type real
      \minimum> 0.0
      \note Enter the pressure corresponding to the Effective leakage ratio entered above.
 N4 ; \field Air Mass Flow Exponent
      \units dimensionless
      \type real
      \default 0.65
      \minimum 0.5
      \maximum 1.0
      \note Enter the exponent used in the air mass flow equation.
```

An IDF example is provided below:

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT LEAKAGE RATIO,
    Zone1ELA,                !- Name of Effective Leakage Ratio
    0.043527,                !- Effective Leakage Ratio {dimensionless}
    1.0,                     !- Maximum Flow Rate {m3/s}
    4.0,                     !- Reference Pressure Difference {Pa}
    0.65;                    !- Air Mass Flow Exponent {dimensionless}
```

AirflowNetwork:Distribution:Component Duct

This object represents a duct component and requires 9 input fields, one alpha field and 8 numeric fields. The relationship between pressure and airflow across the component may be expressed as (2001 ASHRAE Handbook of Fundamentals, Chapter 34):

$$\dot{m} = \sqrt{\frac{2\rho A^2 \Delta P}{fL/D + \sum C_d}}$$

where

$\dot{m}$ = Mass flow rate of air through the component [kg/s]

ρ = Air density [kg/m^3]

A = Cross sectional area [m^2]

ΔP = Total pressure loss across the component [Pa]

L = Duct length [m]

D = Hydraulic diameter [m]

C_d = Dynamic loss coefficient due to fitting [dimensionless]

f = Friction factor

The friction factor can be calculated using the nonlinear Colebrook equation (ASHRAE Handbook of Fundamentals, 1997. p. 2.9, Eq. 29b)

$$\frac{1}{\sqrt{f}} = 1.44 + 2*\log\left(\frac{D}{\varepsilon}\right) - 2*\log\left(1 + \frac{9.3}{\mathrm{Re}*\varepsilon/D*\sqrt{f}}\right)$$

where

ε = Surface roughness [m]

Re = Reynolds number = $\rho VD / \mu$

Field: Name of Duct Component

A unique name for an AirflowNetwork duct component in an air distribution system. This unique name will be referenced by an AirflowNetwork:Distribution:Linkage object to represent a component.

Field: Duct Length

This numeric field is used to input duct length [m]. This value must be greater than zero.

Field: Hydraulic Diameter

This numeric field is used to input hydraulic diameter, which is defined as:

$$D_h = \frac{4A}{P}$$

where

D_h = Hydraulic diameter [m]

A = Duct cross sectional area [m^2]

P = Perimeter of cross section [m]

Field: Cross Section Area

This numeric field is used to input cross section area [m^2]. The model assumes that this element has no area change along its length. Otherwise, effective cross sectional area is required.

Field: Surface Roughness

This numeric field is used to input surface roughness [m]. This value must be greater than zero, and the default value is 0.0009 m.

Field: Coefficient for local dynamic loss due to fitting

This numeric field is defined as a coefficient for dynamic loss [dimensionless]. It represents dynamic loss due to fittings (such as an elbow).

Field: Overall heat transmittance coefficient (U value) from air to air

This numeric field is defined as the overall heat transmittance coefficient (U value, W/m^2-K) from air to air, including film coefficients at both surfaces.

Field: Overall moisture transmittance coefficient from air to air

This numeric field is defined as the overall moisture transmittance coefficient (kg/m^2) from air to air, including film coefficients at both surfaces.

Below is the input data dictionary description for the AirflowNetwork:Distribution: Component Duct object.

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT DUCT,
      \min-fields 8
      \memo This object defines the relationship between pressure and air flow through the duct.
 A1 , \field Name of Duct Component
      \required-field
      \type alpha
      \reference AirflowNetwork ComponentNames
      \note Enter a unique name for this object.
 N1 , \field Duct Length
      \required-field
      \type real
      \units m
      \minimum> 0.0
      \note Enter the length of the duct.
 N2 , \field Hydraulic Diameter
      \required-field
      \type real
      \units m
      \minimum> 0.0
      \note Enter the hydraulic diameter of the duct.
      \note Hydraulic diameter is defined as 4 multiplied by cross section area divided by
      \note perimeter
 N3 , \field Cross Section Area
      \required-field
      \type real
      \units m2
      \minimum> 0.0
      \note Enter the cross section area of the duct.
 N4 , \field Surface Roughness
      \type real
      \units m
      \default 0.0009
      \minimum> 0.0
      \note Enter the inside surface roughness of the duct.
 N5 , \field Coefficient for local dynamic loss due to fitting
      \type real
      \units dimensionless
      \default 0.0
      \minimum 0.0
      \note Enter the coefficient used to calculate dynamic losses of fittings (e.g. elbows).
 N6 , \field Overall heat transmittance coefficient (U value) from air to air
      \Note including film coefficients at both surfaces
      \type real
      \units W/m2-K
      \minimum> 0.0
      \default 0.772
      \note Enter the overall U-value for this duct.
      \note Default value of 0.772 is equivalent to 1.06 m2-K/W (R6) duct insulation with
      \note film coefficients for outside and inside equal to 5 and 25 W/m2-K, respectively.
 N7 ; \field Overall moisture transmittance coefficient from air to air
      \type real
      \units kg/m2
      \minimum> 0.0
      \default 0.001
      \note Enter the overall moisture transmittance coefficient
      \note including moisture film coefficients at both surfaces.
```

An IDF example is provided below:

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT DUCT,
    MainTruck1,              !- Name of Duct Component
    3.0,                     !- Duct Length {m}
    0.6,                     !- Hydraulic Diameter {m}
    0.2827,                  !- Cross Section Area {m2}
    0.0009,                  !- Surface Roughness {m}
    0.01,                    !- Coefficient for local dynamic loss due to fitting {dimensionless}
    0.772,                   !- Overall heat transmittance coefficient (U value) from air to air
                             !- {W/m2-K}
    0.0001;                  !- Overall moisture transmittance coefficient from air to air {kg/m2}
```

AirflowNetwork:Distribution:Component Constant Volume Fan

This component represents a constant volume fan. The air flow rate and air conditions (temperature and humidity) are obtained from the associated FAN: SIMPLE:ConstVolume object.

Field: Name of Constant Volume Fan

The name identifying an AirflowNetwork constant volume fan in an air distribution system. This name must be the same as the name of the associated FAN:SIMPLE:ConstVolume object. This name will be referenced by an AirflowNetwork:Distribution:Linkage object to represent a component.

Below is the input data dictionary description for the AirflowNetwork:Distribution: Component Constant Volume Fan object.

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT CONSTANT VOLUME FAN,
      \min-fields 1
      \memo This object defines the name of the constant volume fan used in an air loop.
 A1 ; \field Name of Constant Volume Fan
      \required-field
      \type alpha
      \object-list FansCV
      \reference AirflowNetwork ComponentNames
      \note Enter the name of the constant volume fan in the primary air loop.
```

An IDF example is provided below:

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT CONSTANT VOLUME FAN,
    Supply Fan 1;            !- Name of Constant Volume Fan
```

AirflowNetwork:Distribution:Component Coil

This component represents a cooling or heating coil. The main purpose for this object is to get calculated values (air flow and temperature/humidity conditions) from the associated coil models.

Field: Name of Associated EnergyPlus Coil

The name identifying an AirflowNetwork cooling coil or heating coil defined in an air loop. This name must be the same name as the associated coil object. This unique name will be referenced by an AirflowNetwork:Distribution:Linkage object to represent a component.

Field: EnergyPlus Coil Type

This field requires input of the coil type used in the AirflowNetwork model. The available choices are:

- COIL:DX:COOLINGBYPASSFACTOREMPIRICAL
- COIL:GAS:HEATING
- COIL:ELECTRIC:HEATING

Field: Air Path Length

This numeric field is used to input air path length for the coil [m]. This value must be greater than 0 meters.

Field: Air Path Hydraulic Diameter

This numeric field is used to input hydraulic diameter of a coil's air path, which is defined as:

$$D_h = \frac{4A}{P}$$

where

D_h = Hydraulic diameter [m]

A = Duct cross section area [m^2]

P = Perimeter of cross section [m]

It should be noted that the relationship for this component between airflow and pressure is similar to the component AirflowNetwork:Distribution:Component Duct. However, the model assumes very small surface roughness (10^{-4}) and no local dynamic loss due to fittings for this component. Therefore, this component only requires two numerical fields. Heat and moisture exchange from surroundings is ignored.

Below is the input data dictionary description for the AirflowNetwork:Distribution: Component Coil object.

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT COIL,
      \min-fields 4
      \memo This object defines the name of a coil used in an air loop.
 A1 , \field Name of Associated EnergyPlus Coil
      \required-field
      \type alpha
      \reference AirflowNetwork ComponentNames
      \note Enter the name of a cooling or heating coil in the primary air loop.
 A2 , \field EnergyPlus Coil Type
      \required-field
      \type choice
      \Key COIL:DX:COOLINGBYPASSFACTOREMPIRICAL
      \Key COIL:GAS:HEATING
      \Key COIL:ELECTRIC:HEATING
      \note Select the type of coil corresponding to the name entered in the field above.
 N1 , \field Air Path Length
      \required-field
      \type real
      \units m
      \minimum> 0
      \note Enter the air path length (depth) for the coil.
 N2 ; \field Air Path Hydraulic Diameter
      \required-field
      \units m
      \type real
      \minimum> 0
      \note Enter the hydraulic diameter of this coil. The hydraulic diameter is
      \note defined as 4 multiplied by the cross section area divided by perimeter.
```

An IDF example is provided below:

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT COIL,
    ACDXCoil 1,                          !- Name of Associated EnergyPlus Coil
    COIL:DX:CoolingBypassFactorEmpirical,  !- EnergyPlus Coil Type
    0.1,                                 !- Air Path Length {m}
    1.00;                                !- Air Path Hydraulic Diameter {m}
```

AirflowNetwork:Distribution:Component Terminal Unit

This component represents a terminal unit for reheating the incoming supply air. The main purpose is to get calculated values from the terminal unit models.

Field: Name of Associated EnergyPlus Terminal Unit

A name identifying an AirflowNetwork terminal unit defined in a zone equipment list. This name must be the same as the associated terminal unit object. This unique name will be referenced by an AirflowNetwork:Distribution:Linkage object to represent a component.

Field: EnergyPlus Terminal Unit Type

This field requires input of the terminal unit type used in the AirflowNetwork model. The only available type is SINGLE DUCT:CONST VOLUME:REHEAT.

Field: Air Path Length

This numeric field is used to input the air path length for the terminal unit [m]. This value must be greater than 0 meters.

Field: Air Path Hydraulic Diameter

This numeric field is used to input hydraulic diameter for the terminal unit's air path, which is defined as:

$$D_h = \frac{4A}{P}$$

where

D_h = Hydraulic diameter [m]

A = Duct cross section area [m^2]

P = Perimeter of cross section [m]

For this component, the relationship between airflow and pressure is similar to the component AirflowNetwork:Distribution:Component Duct. However, the model assumes very small surface roughness (10^{-4}) and no local dynamic loss due to fittings for this component. Therefore, this component only requires two numerical fields. Heat and moisture exchange from surroundings is ignored.

Below is the input data dictionary description for the AirflowNetwork:Distribution: Component Terminal Unit object.

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT TERMINAL UNIT,
      \min-fields 4
      \memo This object defines the name of a terminal unit in an air loop.
 A1 , \field Name of Associated Energyplus Terminal Unit
      \required-field
      \type alpha
      \reference AirflowNetwork ComponentNames
      \note Enter the name of a terminal unit in the primary air loop.
 A2 , \field EnergyPlus Terminal Unit Type
      \required-field
      \type choice
      \Key SINGLE DUCT:CONST VOLUME:REHEAT
      \note Select the type of terminal unit corresponding to the name entered in the field above.
 N1 , \field Air Path Length
      \required-field
      \type real
      \units m
      \minimum> 0
      \note Enter the air path length (depth) for the terminal unit.
 N2 ; \field Air Path Hydraulic Diameter
      \required-field
      \units m
      \type real
      \minimum> 0
      \note Enter the hydraulic diameter of this terminal unit. The hydraulic diameter is
      \note defined as 4 multiplied by the cross section area divided by perimeter.
```

An IDF example is provided below:

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT TERMINAL UNIT,
    Reheat Zone 1,                   !- Name of Associated Energyplus Terminal Unit
    SINGLE DUCT:CONST VOLUME:REHEAT,  !- EnergyPlus Terminal Unit Type
    0.1,                             !- Air Path Length {m}
    0.44;                            !- Air Path Hydraulic Diameter {m}
```

AirflowNetwork:Distribution:Component Constant Pressure Drop

This component represents a constant pressure drop component. It is generally used to simulate a constant pressure drop filter. The mathematical equation may be written as:

$$\Delta P = const$$

Field: Name of Constant Pressure Drop Component

A unique name identifying an AirflowNetwork constant pressure drop component in an air distribution system. This unique name will be referenced by an AirflowNetwork: Distribution:Linkage object to represent a component.

Field: Pressure Difference across the Component

This numeric field is used to input the pressure difference across the element [Pa].

> Note: This object should be used with caution. Each node connected to this object can not be a node for a mixer or splitter, a node in an air primary loop, or a node in a zone configuration loop. It is recommended that duct components be specified at both ends of this object.

Below is the input data dictionary description for the AirflowNetwork:Distribution: Component Constant Pressure Drop object.

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT CONSTANT PRESSURE DROP,
      \min-fields 3
      \memo This object defines the characteristics of a constant pressure drop component
      \memo (e.g. filter). Each node connected to this object can not be a node of mixer,
      \memo splitter, a node of air primary loop, or zone equipment loop. It is recommended
      \memo to connect to a duct component at both ends.
 A1 , \field Name of Constant Pressure Drop Component
      \required-field
      \type alpha
      \reference AirflowNetwork ComponentNames
      \note Enter a unique name for this object.
 N1 ; \field Pressure Difference Across the Component
      \required-field
      \units Pa
      \type real
      \minimum> 0.0
      \note Enter the pressure drop across this component.
```

An IDF example is provided below:

```
AIRFLOWNETWORK:DISTRIBUTION:COMPONENT CONSTANT PRESSURE DROP,
 SupplyCPDComp, ! Name of Constant Pressure Drop Component
 1.0;           ! Pressure Difference Across the Component [Pa]
```

AirflowNetwork:Distribution:Linkage

The AirflowNetwork:Distribution:linkage represents a connection between two AirflowNetwork:Distribution:Node objects and an AirflowNetwork component defined above. In addition, the relative height from node height to linkage height for each node is required.

Field: Name of linkage

The name identifies the linkage for later reference and in the output listing. Each linkage should have a unique name.

Field: Node 1 Name

Designates a node name where airflow starts. The node name should be defined in an AirflowNetwork:Distribution:Node object.

Field: Node 2 Name

Designates a node name where airflow ends. The node name should be defined in an AirflowNetwork:Distribution:Node object.

Field: Component Name

Designates an AirflowNetwork component name associated with the two nodes. The component name should be one of the AirflowNetwork:Distribution:Component… object names.

Field: Thermal Zone Name

Designates a thermal zone where the linkage is located. The information provides the ambient conditions for duct elements to calculate duct conduction losses (only used if component is AirflowNetwork:Distribution:Component Duct).

Below is the input data dictionary description for the AirflowNetwork:Distribution: Linkage object.

```
AIRFLOWNETWORK:DISTRIBUTION:LINKAGE,
      \min-fields 6
      \memo This object defines the connection between two nodes and a component.
 A1 , \field Name of Linkage
      \required-field
      \type alpha
      \note Enter a unique name for this object.
      \reference AirflowNetwork LinkageNames
 A2 , \field Node 1 Name
      \required-field
      \type alpha
      \object-list AirflowNetwork NodeNames
      \object-list ZoneNames
      \note Enter the name of zone or AirFlowNetwork node.
 A3 , \field Node 2 Name
      \required-field
      \type alpha
      \object-list AirflowNetwork NodeNames
      \object-list ZoneNames
      \note Enter the name of zone or AirFlowNetwork node.
 A4 , \field Component Name
      \required-field
      \type object-list
      \object-list AirflowNetwork ComponentNames
      \note Enter the name of an AirflowNetwork Component. A component is one of the
      \note following AIRFLOWNETWORK:DISTRIBUTION:COMPONENT objects: LEAK, LEAKAGE RATIO,
      \note DUCT, CONSTANT VOLUME FAN, COIL, TERMINAL UNIT, or CONSTANT PRESSURE DROP.
 A5 ; \field Thermal Zone Name
      \type object-list
      \object-list ZoneNames
      \note Only used if component = AIRFLOWNETWORK:DISTRIBUTION:COMPONENT DUCT
      \note The zone name is where COMPONENT DUCT is exposed. Leave this field blank if the
      \note duct conduction loss is ignored.
```

An IDF example is provided below:

```
AIRFLOWNETWORK:DISTRIBUTION:LINKAGE,
    Main Link 1,             !- Name of Linkage
    EquipmentInletNode,      !- Node 1 Name
    SupplyMainNode,          !- Node 2 Name
    MainTruck1,              !- Component Name
    Attic Zone;              !- Thermal Zone Name
```

AirflowNetwork Outputs

The AirflowNetwork node used in the following output variables includes zones defined in AirflowNetwork:Multizone:Zone objects, external nodes defined in

AirflowNetwork:Multizone:External Node objects, and nodes defined in AirflowNetwork:Distribution:Node objects.

The AirflowNetwork linkage used in following output variables includes surfaces defined in AirflowNetwork:Multizone:Surface objects, and linkages defined in AirflowNetwork:Distribution:Linkage objects. The surface linkages represent airflows through surface cracks or openings between two zones or between a zone and outdoors. The distribution linkages represent airflows in an air distribution system.

```
HVAC,Average,AirflowNetwork Node Temperature [C]
HVAC,Average,AirflowNetwork Node Humidity Ratio [kg/kg]
HVAC,Average,AirflowNetwork Node Total Pressure [Pa]
HVAC,Average,AirflowNetwork Wind Pressure [Pa]
HVAC,Average,AirflowNetwork Mass Flow Rate from Node 1 to 2 [kg/s]
HVAC,Average,AirflowNetwork Mass Flow Rate from Node 2 to 1 [kg/s]
HVAC,Average,AirflowNetwork Volume Flow Rate from Node 1 to 2 [m^3/s]
HVAC,Average,AirflowNetwork Volume Flow Rate from Node 2 to 1 [m^3/s]
HVAC,Average,AirflowNetwork Linkage Pressure Difference [Pa]
HVAC,Average,Window/Door Venting Opening Factor
HVAC,Average,Opening Factor Multiplier for Venting Modulation []
HVAC,Average,Inside Temp Setpoint for AirflowNetwork Venting [C]
HVAC,Average,Venting Availability []
HVAC,Average,AirflowNetwork Infiltration Sensible Gain Rate [W]
HVAC,Sum,AirflowNetwork Infiltration Sensible Gain [J]
HVAC,Average,AirflowNetwork Mixing Sensible Gain Rate [W]
HVAC,Sum,AirflowNetwork Mixing Sensible Gain [J]
HVAC,Average,AirflowNetwork Infiltration Sensible Loss Rate [W]
HVAC,Sum,AirflowNetwork Infiltration Sensible Loss [J]
HVAC,Average,AirflowNetwork Mixing Sensible Loss Rate [W]
HVAC,Sum,AirflowNetwork Mixing Sensible Loss [J]
HVAC,Average,AirflowNetwork Infiltration Latent Gain Rate [W]
HVAC,Sum,AirflowNetwork Infiltration Latent Gain [J]
HVAC,Average,AirflowNetwork Infiltration Latent Loss Rate [W]
HVAC,Sum,AirflowNetwork Infiltration Latent Loss [J]
HVAC,Average,AirflowNetwork Mixing Latent Gain Rate [W]
HVAC,Sum,AirflowNetwork Mixing Latent Gain [J]
HVAC,Average,AirflowNetwork Mixing Latent Loss Rate [W]
HVAC,Sum,AirflowNetwork Mixing Latent Loss [J]
HVAC,Average,AirflowNetwork Duct Leak Sensible Gain Rate [W]
HVAC,Sum,AirflowNetwork Duct Leak Sensible Gain [J]
HVAC,Average,AirflowNetwork Duct Leak Sensible Loss Rate [W]
HVAC,Sum,AirflowNetwork Duct Leak Sensible Loss [J]
HVAC,Average,AirflowNetwork Duct Leak Latent Gain Rate [W]
HVAC,Sum,AirflowNetwork Duct Leak Latent Gain [J]
HVAC,Average,AirflowNetwork Duct Leak Latent Loss Rate [W]
HVAC,Sum,AirflowNetwork Duct Leak Latent Loss [J]
HVAC,Average,AirflowNetwork Duct Conduction Sensible Gain Rate [W]
HVAC,Sum,AirflowNetwork Duct Conduction Sensible Gain [J]
HVAC,Average,AirflowNetwork Duct Conduction Sensible Loss Rate [W]
HVAC,Sum,AirflowNetwork Duct Conduction Sensible Loss [J]
HVAC,Average,AirflowNetwork Duct Diffusion Latent Gain Rate [W]
HVAC,Sum,AirflowNetwork Duct Diffusion Latent Gain [J]
HVAC,Average,AirflowNetwork Duct Diffusion Latent Loss Rate [W]
HVAC,Sum,AirflowNetwork Duct Diffusion Latent Loss [J]
HVAC,Average,AirflowNetwork Distribution Sensible Gain Rate [W]
HVAC,Sum,AirflowNetwork Distribution Sensible Gain [J]
HVAC,Average,AirflowNetwork Distribution Sensible Loss Rate [W]
HVAC,Sum,AirflowNetwork Distribution Sensible Loss [J]
HVAC,Average,AirflowNetwork Distribution Latent Gain Rate [W]
HVAC,Sum,AirflowNetwork Distribution Latent Gain [J]
HVAC,Average,AirflowNetwork Distribution Latent Loss Rate [W]
HVAC,Sum,AirflowNetwork Distribution Latent Loss [J]
HVAC,Sum,AirflowNetwork Zone Infiltration Volume [m3]
HVAC,Sum,AirflowNetwork Zone Infiltration Mass [kg]
HVAC,Average,AirflowNetwork Zone Infiltration Air Change Rate [ach]
HVAC,Sum,AirflowNetwork Zone Mixing Volume [m3]
HVAC,Sum,AirflowNetwork Zone Mixing Mass [kg]
```

AirflowNetwork Node Temperature [C]

This is the AirflowNetwork node temperature output in degrees C.

AirflowNetwork Node Humidity Ratio [kg/kg]

This is the AirflowNetwork node humidity ratio output in kg/kg.

AirflowNetwork Node Total Pressure [Pa]

This is the AirflowNetwork nodal total pressure output in Pa with respect to outdoor barometric pressure. The total pressure is the sum of static pressure, dynamic pressure, and elevation impact at the node's relative height.

AirflowNetwork Wind Pressure [Pa]

This is the AirflowNetwork wind pressure output in Pa. The wind pressure depends on several factors, including wind speed, wind direction, the wind-pressure coefficient (Cp) values for the AirflowNetwork:Multizone:External Node associated with the heat transfer surface and the site wind conditions.

When Wind Pressure Coefficient Type = "INPUT" in the AIRFLOWNETWORK SIMULATION object, the output represents external node pressures driven by wind defined in an AirflowNetwork:Multizone:External Node object. When Wind Pressure Coefficient Type = "SURFACE-AVERAGE CALCULATION" in AIRFLOWNETWORK SIMULATION, the program assumes five external nodes:

FACADE1	Representing north orientation
FACADE2	Representing east orientation
FACADE3	Representing south orientation
FACADE4	Representing west orientation
ROOF	Representing horizontal orientation

In this case, the output represents the wind pressures for the five external nodes defined above.

AirflowNetwork Mass Flow Rate from Node 1 to 2 [kg/s]

This is the AirflowNetwork linkage mass flow rate output in kg/s in the direction from Node 1 to Node 2. It reports surface airflows through a crack or opening, and through linkages defined in an AirflowNetwork:Distribution:Linkage object. The surface linkage is divided into two types of surfaces, exterior surface and interior surface. Node 1 for an exterior surface linkage is a thermal zone and Node 2 is an external node. The value of AirflowNetwork Mass Flow Rate from Node 1 to 2 represents the flow rate from a thermal zone to outdoors. The flow direction through an interior surface crack or opening is defined from a thermal zone defined by a surface's InsideFaceEnvironment (Node 1) to an adjacent thermal zone defined by a surface's OutsideFaceEnvironment (Node 2). For an AirflowNetwork:Distribution:Linkage object, the value represents the air mass flow rate flowing from Node 1 to Node 2.

It should be pointed out that in general, each linkage has one directional flow at any given time, either from Node 1 to 2 or from Node 2 to 1. However, there are two components which may have flows in both directions simultaneously: AirflowNetwork:Multizone:Component Detailed Opening and AirflowNetwork:Multizone:Component Simple Opening.

AirflowNetwork Mass Flow Rate from Node 2 to 1 [kg/s]

This is the AirflowNetwork linkage mass flow rate output in kg/s in the direction from Node 2 to Node 1. It reports airflows from surfaces through a crack or opening, and from linkages defined in an AirflowNetwork:Distribution:Linkage object. Node 1 and Node 2 for a surface or subsurface are defined in the same manner as AirflowNetwork Mass Flow Rate from Node 1 to 2.

AirflowNetwork Volume Flow Rate from Node 1 to 2 [m^3/s]

This is the AirflowNetwork linkage volume flow rate output in m^3/s in the direction from the Node 1 to Node 2. It is defined in the same manner as AirflowNetwork Mass Flow Rate from Node 1 to 2.

AirflowNetwork Volume Flow Rate from Node 2 to 1 [m^3/s]

This is the AirflowNetwork linkage volume flow rate output in m^3/s in the direction from Node 2 to Node 1. It is defined in the same manner as AirflowNetwork Mass Flow Rate from Node 2 to 1.

AirflowNetwork Linkage Pressure Difference [Pa]

This is the pressure difference across a linkage in Pa. The linkage includes both objects: AirflowNetwork:Multizone:Surface and AirflowNetwork: Distribution:Linkage.

Window/Door Venting Opening Factor []

The current time-step value of the venting opening factor for a particular window or door. When the window or door is venting, this is the input value of the opening factor (see AirflowNetwork:Multizone:Surface, Window/Door Opening Factor) times the multiplier for venting modulation (see description of next output variable, "Opening Factor Multiplier for AirflowNetwork Venting Modulation"). For example, if the input Window/Door opening factor is 0.5 and the modulation multiplier is 0.7, then the value of this output variable will be 0.5x0.7 = 0.35.

Opening Factor Multiplier for AirflowNetwork Venting Modulation []

This is the multiplier on a window or door opening factor when venting modulation is in effect. See "Modulation of Openings" under AirflowNetwork:Multizone:Zone for a description of how the multiplier is determined.

When modulation is in effect the value of the multiplier is between 0.0 and 1.0. When modulation does not apply the value of the multiplier may be –1.0. When modulation applies but the surface is not venting, the value is –1.0. This is summarized in the following table. In this table, "Zone" means a thermal zone for which AirflowNetwork:Multizone:Zone has been specified. See AirflowNetwork: Multizone:Zone for definition of "Ventilation Control Mode."

Table 2. Value of opening factor multiplier for different venting conditions.

Is surface in a Zone?	**Ventilation Control Mode**	**Is surface venting?**	**Value of opening factor multiplier**
Yes	TEMPERATURE	Yes	0.0 to 1.0
		No	-1.0
	ENTHALPIC	Yes	0.0 to 1.0
		No	-1.0
	CONSTANT	Yes	1.0
	NOVENT	No	-1.0

Inside Temp Setpoint for AirflowNetwork Venting [C]

The time-step value of the venting setpoint temperature for the zone to which the surface belongs. This setpoint is determined from the Vent Temperature Schedule input (ref: AirflowNetwork:Multizone:Zone).

Venting Availability [ ]

A value of 1.0 means venting through the surface can occur if venting control conditions are satisfied. A value of 0.0 means venting through the surface cannot occur under any circumstances. This value is determined by the Venting Availability Schedule input (ref: AirflowNetwork:Multizone:Zone or AirflowNetwork:Multizone: Surface).

AirflowNetwork Infiltration Sensible Gain Rate [W]

The average convective sensible heat gain rate, in Watts, to the zone air corresponding to the Zone Infiltration Volume averaged over the reporting period. This value is calculated for each time step when the outdoor dry bulb temperature is higher than the zone temperature, otherwise the sensible gain rate is set to 0.

AirflowNetwork Infiltration Sensible Loss Rate [W]

The average convective sensible heat loss rate, in Watts, to the zone air corresponding to the Zone Infiltration Volume averaged over the reporting period.

AirflowNetwork Infiltration Latent Gain Rate [W]

The average convective latent heat gain rate, in Watts, to the zone air corresponding to the Zone Infiltration Volume averaged over the reporting period, when the outdoor humidity ratio is higher than the zone air humidity ratio.

AirflowNetwork Infiltration Latent Gain [J]

The total convective latent heat gain, in Joules, to the zone air corresponding to the Zone Infiltration Volume summed over the reporting period.

AirflowNetwork Infiltration Latent Loss Rate [W]

The average convective latent heat loss rate, in Watts, to the zone air corresponding to the Zone Infiltration Volume averaged over the reporting period.

AirflowNetwork Infiltration Latent Loss [J]

The total convective latent heat loss, in Joules, to the zone air corresponding to the Zone Infiltration Volume summed over the reporting period.

AirflowNetwork Mixing Sensible Gain Rate [W]

The average convective sensible heat gain rate, in Watts, to the zone air corresponding to the Zone Mixing Volume averaged over the reporting period. The mixing-volume is defined as incoming volume flow from other adjacent zones where the air temperature is higher than the temperature in this zone. For example, there are two zones (Zone 2 and Zone 3) adjacent to this zone (Zone 1). Zone 1 receives airflows from both Zone 2 and Zone 3. The air temperature is 21°C in Zone 1. The air temperatures are 20°C in Zone 2 and 22°C in Zone 3. The sensible gain rate only includes heat gain from Zone 3 with respect to Zone 1. The energy received from Zone 2 is considered as a sensible loss, instead of a gain, because the air temperature in Zone 2 is lower than in Zone 1.

AirflowNetwork Mixing Sensible Loss Rate [W]

The average convective sensible heat loss rate, in Watts, to the zone air corresponding to the Zone Mixing Volume averaged over the reporting period.

AirflowNetwork Mixing Sensible Gain [J]

The total convective sensible heat gain, in Joules, to the zone air corresponding to the Zone Mixing Volume summed over the reporting period.

AirflowNetwork Mixing Sensible Loss [J]

The total convective sensible heat loss, in Joules, to the zone air corresponding to the Zone Mixing Volume summed over the reporting period.

AirflowNetwork Mixing Latent Gain Rate [W]

The average convective latent heat gain rate, in Watts, to the zone air corresponding to the Zone Mixing Volume averaged over the reporting period.

AirflowNetwork Mixing Latent Gain [J]

The total convective latent heat gain, in Joules, to the zone air corresponding to the Zone Mixing Volume summed over the reporting period.

AirflowNetwork Mixing Latent Loss Rate [W]

The average convective latent heat loss rate, in Watts, to the zone air corresponding to the Zone Mixing Volume averaged over the reporting period.

AirflowNetwork Mixing Latent Loss [J]

The total convective latent heat loss, in Joules, to the zone air corresponding to the Zone Mixing Volume summed over the reporting period.

AirflowNetwork Duct Leak Sensible Gain Rate [W]

This is the average sensible heat gain rate, in Watts, to a specific zone due to supply air leaks from the forced air distribution system. This value is averaged over the reporting period. A sensible heat gain occurs when duct air is warmer than zone air. It should be pointed out that when multiple supply air leaks are present in a single zone, the output value is the summation of all the supply air leak gains in this zone.

AirflowNetwork Duct Leak Sensible Gain [J]

This is the total sensible heat gain, in Joules, to a specific zone due to supply air leaks summed over the reporting period.

AirflowNetwork Duct Leak Sensible Loss Rate [W]

This is the average sensible heat loss rate, in Watts, to a specific zone due to supply air leaks from the forced air distribution system. This value is averaged over the reporting period. A sensible heat loss occurs when duct air is cooler than zone air. It should be pointed out that when multiple supply air leaks are present in this zone, the output value is the summation of all the supply air leak losses in this zone.

AirflowNetwork Duct Leak Sensible Loss [J]

This is the total sensible heat loss, in Joules, to a specific zone due to supply air leaks summed over the reporting period.

AirflowNetwork Duct Leak Latent Gain Rate [W]

This is the average latent heat gain rate, in Watts, to a specific zone due to supply air leaks from the forced air distribution system for the reported time period.

AirflowNetwork Duct Leak Latent Gain [J]

This is the total latent heat gain, in Joules, to a specific zone due to supply air leaks summed over the reporting period.

AirflowNetwork Duct Leak Latent Loss Rate [W]

This is the average latent heat loss rate, in Watts, to a specific zone due to supply air leaks from the forced air distribution system for the reported time period.

AirflowNetwork Duct Leak Latent Loss [J]

This is the total latent heat loss, in Joules, to a specific zone due to supply air leaks summed over the reporting period.

AirflowNetwork Duct Conduction Sensible Gain Rate [W]

This is the average sensible heat gain rate, in Watts, of duct conduction to a specific zone where the ducts are located. This value is averaged over the reporting period. A sensible heat gain occurs when duct air is warmer than the zone air. It should be pointed out that when ducts are located in different zones, the total duct conduction loss should be the summation of the duct conduction losses in these zones.

AirflowNetwork Duct Conduction Sensible Gain [J]

This is the total sensible heat gain, in Joules, to a specific zone due to duct conduction summed over the reporting period.

AirflowNetwork Duct Conduction Sensible Loss Rate [W]

This is the average sensible heat loss rate, in Watts, of duct conduction to a specific zone where the ducts are located. This value is averaged over the reporting period. A sensible heat loss occurs when duct air is cooler than the zone air.

AirflowNetwork Duct Conduction Sensible Loss [J]

This is the total sensible heat loss, in Joules, to a specific zone due to duct conduction summed over the reporting period.

AirflowNetwork Duct Diffusion Latent Gain Rate [W]

This is the average latent heat gain rate, in Watts, of vapor diffusion through the walls of the air distribution system to a specific zone where the ducts are located. This value is averaged over the reporting period.

AirflowNetwork Duct Diffusion Latent Gain [J]

This is the total latent heat gain, in Joules, to a specific zone due to duct vapor diffusion summed over the reporting period.

AirflowNetwork Duct Diffusion Latent Loss Rate [W]

This is the average latent heat loss rate, in Watts, of duct vapor diffusion to a specific zone where the ducts are located. This value is averaged over the reporting period.

AirflowNetwork Duct Diffusion Latent Loss [J]

This is the total latent heat loss, in Joules, to a specific zone due to duct vapor diffusion summed over the reporting period.

AirflowNetwork Distribution Sensible Gain Rate [W]

This is the average total sensible heat gain rate, in Watts, in a specific zone caused by the forced air distribution system. The total sensible gain rate is the sum of duct leakage sensible gain rate and duct conduction sensible gain rate. This value is averaged over the reporting period. The multizone airflow sensible gain rate is excluded in this output report variable. The output of multizone airflow sensible gain is reported in the previously-described output variables AirflowNetwork Infiltration Sensible Gain Rate and AirflowNetwork Mixing Sensible Gain Rate.

AirflowNetwork Distribution Sensible Gain [J]

This is the total sensible heat gain, in Joules, in a specific zone caused by the forced air distribution system. The total sensible gain is the sum of duct leakage sensible gain and duct conduction sensible gain. This value is summed over the reporting period. The multizone airflow sensible gain is excluded in this output report variable. The output of multizone airflow sensible gain is reported in the previously-described output variables AirflowNetwork Infiltration Sensible Gain and AirflowNetwork Mixing Sensible Gain.

AirflowNetwork Distribution Sensible Loss Rate [W]

This is the average total sensible heat loss rate, in Watts, in a specific zone caused by the forced air distribution system. The total sensible loss rate is the sum of duct leakage sensible loss rate and duct conduction sensible loss rate. This value is averaged over the reporting period. The multizone airflow sensible loss rate is excluded in this output report variable. The output of multizone airflow sensible loss rate is reported in the previously-described output variables AirflowNetwork Infiltration Sensible Loss Rate and AirflowNetwork Mixing Sensible Loss Rate.

AirflowNetwork Distribution Sensible Loss [J]

This is the total sensible heat loss, in Joules, in a specific zone caused by the forced air distribution system. The total sensible loss is the sum of duct leakage sensible loss and duct conduction sensible loss. This value is summed over the reporting period. The multizone airflow sensible loss is excluded in this output report variable. The output of multizone airflow sensible loss is reported in the previously-described output variables AirflowNetwork Infiltration Sensible Loss and AirflowNetwork Mixing Sensible Loss.

AirflowNetwork Distribution Latent Gain Rate [W]

This is the average total latent heat gain rate, in Watts, in a specific zone caused by the forced air distribution system. The total latent gain rate is the sum of duct leakage latent gain rate and duct conduction latent gain rate. This value is averaged over the reporting period.

AirflowNetwork Distribution Latent Gain [J]

This is the total latent heat gain, in Joules, in a specific zone caused by the forced air distribution system. The total latent gain is the sum of duct leakage latent gain and duct diffusion latent gain. This value is summed over the reporting period.

AirflowNetwork Distribution Latent Loss Rate [W]

This is the average total latent heat loss rate, in Watts, in a specific zone caused by the forced air distribution system. The total latent loss rate is a sum of duct leakage latent loss rate and duct diffusion latent loss rate. This value is averaged over the reporting period.

AirflowNetwork Distribution Latent Loss [J]

This is the total latent heat loss, in Joules, in a specific zone caused by the forced air distribution system. The total latent loss is the sum of duct leakage latent loss and duct diffusion latent loss. This value is summed over the reporting period.

NOTE: The following report variables should not be confused with similar report variables for the infiltration, mixing, and cross mixing objects (Ref. Infiltration Output, Mixing Output, or Cross Mixing Output). The report variables described below refer to infiltration, mixing, and cross-mixing when an AirflowNetwork Simulation is performed. The following report variables are <u>always</u> used to describe infiltration, mixing, and cross mixing when the AirflowNetwork Control field in the AirflowNetwork Simulation object is set to “Multizone without Distribution” or “Multizone with Distribution”. In this case the report variables for the infiltration, mixing, and cross mixing objects will <u>always</u> be 0.

In contrast, the following report variables are <u>only</u> used to describe infiltration, mixing, and cross mixing when the AirflowNetwork Control field in the AirflowNetwork Simulation object is set to “Multizone Airflow with Distribution Only During Fan Operation” <u>and</u> the fan is operating. When the fan is not operating, the report variables for the infiltration, mixing, and cross mixing objects are used.

In the case where the AirflowNetwork Control field in the AirflowNetwork Simulation object is set to “No Multizone or Distribution”, the following report variables are <u>not</u> used and the report variables for the infiltration, mixing, and cross mixing objects are used instead.

AirflowNetwork Infiltration Sensible Gain [J]

The total convective sensible heat gain, in Joules, to the zone air corresponding to the Zone Infiltration Volume summed over the reporting period. This value is calculated for each time step when the outdoor dry bulb temperature is higher than the zone temperature, otherwise the sensible gain is set to 0.

AirflowNetwork Infiltration Sensible Loss [J]

The total convective sensible heat loss, in Joules to the zone air corresponding to the Zone Infiltration Volume summed over the reporting period.

AirflowNetwork Zone Infiltration Volume [m3]

The volume of outside air flow into the zone from window/door openings and cracks in the exterior surfaces of the zone (i.e., the sum of ventilation and crack flows <u>from the exterior into the zone)</u>. Note that AirflowNetwork Zone Infiltration Volume will be <u>zero</u> if all of the flows through the zone’s exterior surfaces are <u>out</u> of the zone.

AirflowNetwork Zone Infiltration Mass [kg]

The mass of air corresponding to the AirflowNetwork Zone Infiltration Volume.

AirflowNetwork Zone Infiltration Air Change Rate [ach]

The number of air changes per hour produced by outside air flow into the zone from window/door openings and cracks in the exterior surfaces of the zone (i.e. the sum of ventilation and crack flows from the exterior into the zone). Note that, like Zone Infiltration Volume, Zone Infiltration Air Change Rate will be zero if all flow through the zone's exterior surfaces are out of the zone.

AirflowNetwork Zone Mixing Volume [m3]

This is a measure of interzone air flow for each thermal zone. It is the volume of air flow into the zone from adjacent zones through window/door openings and cracks in the interior heat transfer surfaces of the zone. This variable does not include flows that are from the zone to adjacent zones. Note that Zone Mixing Volume will be zero if all flow through the zone's interior surfaces are out of the zone.

AirflowNetwork Zone Mixing Mass [kg]

The mass of air corresponding to the AirflowNetwork Zone Mixing Volume.

Engineering Document for Airflow Network Model

Overview

The AirflowNetwork model provides the ability to simulate the performance of an air distribution system, including supply and return leaks, and calculate multizone airflows driven by outdoor wind and forced air during HVAC system operation. The pressure and airflow model described here was developed based on AIRNET (Walton, 1989). This detailed model is used to simulate thermal conduction and air leakage losses for air distribution systems in residential or light commercial buildings. This model replaces the obsolete models for COMIS and Air Distribution System (ADS). The main difference is that the AirflowNetwork model adopts the obsolete COMIS model approach to introduce envelope leakage at a specific surface and modulate window and door openings at specified input and current outdoor conditions in multizone airflow calculations, instead of lumping all envelope leakage together as the obsolete ADS model does. In addition, the model calculates multizone airflows driven by wind when the HVAC system turns off. This capability is equivalent to the obsolete model of COMIS. The multizone airflow calculations are now performed at the system time step instead of at the zone time step. This enhancement will allow future development of hybrid ventilation system models. In general, the model provides combined capabilities of both COMIS and ADS.

Model Description

The AirflowNetwork model uses an airflow network method, which consists of a set of nodes connected by airflow components through linkages. The objects of AirflowNetwork:Multizone:Zone, AirflowNetwork:Multizone:External Node, and AirflowNetwork:Distribution:Node represent airflow nodes. The objects of AirflowNetwork:Multizone:Surface and AirflowNetwork:Distribution:Linkage represent airflow linkages. The other objects with a relationship between pressure and airflow represent airflow components.

The AirflowNetwork model consists of three consequential steps:

- Pressure and airflow calculations
- Node temperature and humidity calculations
- Sensible and latent load calculations

The pressure and airflow calculations determine pressure at each node and airflow through each linkage given wind pressures and forced airflows. Based on the airflow calculated for each linkage, the model then calculates node temperatures and humidity ratios given zone air temperatures and zone humidity ratios. Using these node temperatures and humidity ratios, the sensible and latent loads from duct system conduction and leakage are summed for each zone. The sensible and latent loads obtained in this step are then used in the zone energy balance equations to predict HVAC system loads and to calculate the final zone air temperatures, humidity ratios, and pressures.

The present AirflowNetwork model may only be applied to a single heating and cooling system that uses a single air distribution system. The model excludes the impact of thermal capacities of the air and duct systems. The impact of thermal capacity will be addressed in future upgrades to this model.

Pressure and airflow calculations

The EnergyPlus airflow network consists of a set of nodes linked by airflow components. Therefore, it is a simplified airflow model, compared to detailed models, such as those used in computational fluid dynamics (CFD) models. The node variable is pressure and the linkage variable is airflow rate. A brief description is presented below. A detailed description of the airflow network model may be found in the work of Walton (1989), Dols and Walton (2002), and Walton and Dols (2003).

Initialization

The Newton's method requires an initial set of values for the node pressures. There are two initialization methods available. The first is linear initialization and equivalent to Initialization flag = 0. These initial values may be obtained by including in each airflow component a linear approximation relating the flow to the pressure drop:

$$\dot{m}_i = C_i \rho * \Delta P_i / \mu$$

where

$\dot{m}_i$	= Air mass flow rate at i-th linkage
C_i	= Air mass flow coefficient
ΔP_i	= Pressure difference across the i-th linkage
μ	= Air viscosity

This initialization handles stack effects very well and tends to establish the proper direction for the airflows. The linear approximation is conveniently provided by the laminar regime.

The second initialization assumes the initial pressures are zero and use the Newton's method directly.

Convergence criteria

Conservation of mass flow rate at each linkage provides the convergence criterion. When the sum of mass flow rates in all the linkages approaches zero within the convergence tolerance, the solution has converged. The solution is assumed to have converged when the sum is less than the convergence value, in order to reduce the number of iterations and obtain sufficient accuracy. There are two convergence criteria used in the AirflowNetwork model: Relative airflow convergence tolerance and Absolute airflow convergence tolerance.

Relative airflow tolerance = $\left| \sum \dot{m}_i \right| \Big/ \sum \left| \dot{m}_i \right|$

Absolute airflow tolerance = $\left| \sum \dot{m}_i \right|$

The relative airflow tolerance is equivalent to the ratio of the absolute value of the sum of all network airflows to the sum of the network airflow magnitudes. The absolute airflow tolerance is the summation of the absolute value of all network airflows. The solution has converged when both of these convergence criteria have been met.

Linkage models

A linkage used in the AirflowNetwork model has two nodes, inlet and outlet, and is linked by a component which has a relationship between airflow and pressure. The pressure difference across each component in a linkage is assumed to be governed by Bernoulli's equation:

$$\Delta P = \left(P_n + \frac{\rho V_n^{\ 2}}{2} \right) - \left(P_m + \frac{\rho V_m^{\ 2}}{2} \right) + \rho g (z_n - z_m)$$

where

ΔP	= Total pressure difference between nodes n and m [Pa]
P_n, P_m	= Entry and exit static pressures [Pa]
V_n, V_m	= Entry and exit airflow velocities [m/s]
ρ	= Air density [kg/m^3]
g	= Acceleration due to gravity [9.81 m/s^2]
z_n, z_m	= Entry and exit elevations [m]

By rearranging terms and adding wind pressure impacts, the above equation may be rewritten in the format used by the airflow network model:

$$\Delta P = P_n - P_m + P_S + P_W$$

where

P_n, P_m	= Total pressures at nodes n and m [Pa]
P_S	= Pressure difference due to density and height differences [Pa]
P_W	= Pressure difference due to wind [Pa]

The Input Output Reference provides the relationship between airflow and pressure for the most of the components (Ref. AirflowNetwork Model). The relationship between airflow and pressure for the AirflowNetwork:Multizone:Component Detailed Opening and AirflowNetwork:Multizone:Component Simple Opening objects are provided in detail in this reference. These components are equivalent to the obsolete COMIS AIR FLOW:OPENING object.

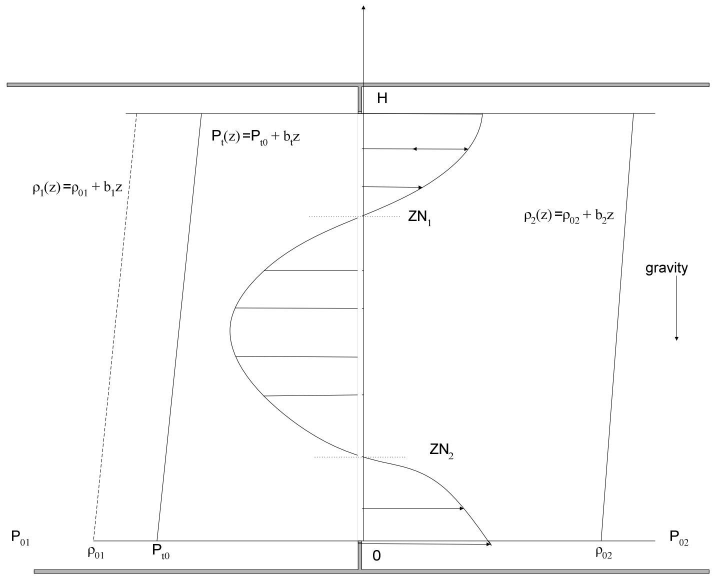


Figure 18. The general problem of gravitational flow through a vertical opening

The schematic drawing of a possible air flow pattern through a vertical opening (AirflowNetwork:Multizone:Component Detailed Opening) is shown in Figure 18. The equations used below are extracted from COMIS Fundamentals.

The air density is assumed to be a linear function of height:

$$\rho_i(z) = \rho_{0i} + b_i z$$

The pressure difference is assumed to be linear and simulate the effect of turbulence:

$$\Delta P_t = P_{t0} + b_t z$$

The reference pressures on each side are given at the bottom of the opening. By assuming the Bernoulli hypothesis on both sides, the pressure difference can be defined at any level of z as:

$$P_1(z) - P_2(z) = (P_{01} - P_{02}) - g\left[(\rho_{01} z + b_1 z^2/2) - (\rho_{02} z + b_2 z^2/2)\right] + (P_{t0} + b_t z)$$

The velocity at any level z is given by

$$v(z) = \sqrt{2\frac{P_1(y) - P_2(y)}{\rho}}$$

The locations of the two possible neutral planes are given by an equilibrium in pressure which leads to a zero velocity point. By assuming the left terms in the equation above to be zero, one may have:

$$g(b_1 - b_2)z^2/2 + \left[g(\rho_{01} - \rho_{02}) - b_t\right]z + (-P_{01} + P_{02} - P_{t0}) = 0$$

This equation above can have two, one, or zero real solutions. The zero solution represents a one way flow through the opening and may be expressed in the following equation:

$$\dot{m} = C_d \theta \int_{z=0}^{z=H} \rho v(z) W dz$$

The one real solution represents a two way (bi-directional) flow, which may be written in the following equations.

$$\dot{m}_{0,z1} = C_d \theta \int_{z=0}^{z=z1} \rho v(z) W dz$$

$$\dot{m}_{z1,H} = C_d \theta \int_{z=z1}^{z=H} \rho v(z) W dz$$

The two real solutions represent a three way flow, which may be written in the following equations.

$$\dot{m}_{z2,H} = C_d \theta \int_{z=z2}^{z=H} \rho v(z) W dz$$

$$\dot{m}_{z1,z2} = C_d \theta \int_{z=z1}^{z=z2} \rho v(z) W dz$$

$$\dot{m}_{z2,H} = C_d \theta \int_{z=z2}^{z=H} \rho v(z) W dz$$

where

C_d = discharge coefficient
θ = Area reduction factor [dimensionless]
W = Opening width [m]

The discharge coefficient, opening width, opening height, and start height factor are modulated based on opening factors. A detailed description of opening factor calculations may be found in the Input Output Reference (Ref. AirflowNetwork:Multizone:Zone, AirflowNetwork:Multizone:Surface, and AirflowNetwork:Multizone:Component Detailed Opening).

The above calculation procedure is used for a normal rectangular window. For a horizontally pivoted rectangular window, the calculation procedure is slightly different. A schematic drawing of a horizontally pivoted window is shown in Figure 19. Schematic drawing of a horizontally pivoted window.

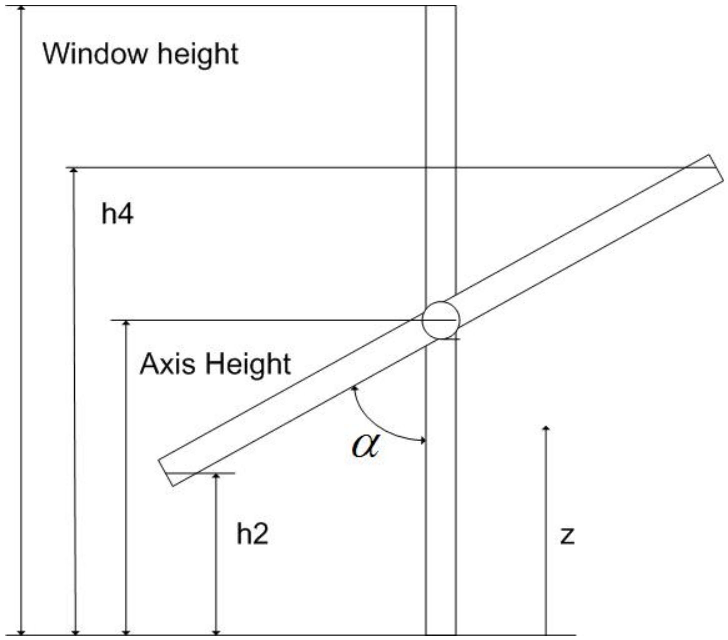


Figure 19. Schematic drawing of a horizontally pivoted window

The opening angle α (0-90°) is linearly proportional to the window opening factor (0-1.0). An opening factor of 1.0 is equal to an opening angle of 90°. The heights in the pivoted area are expressed as:

$$h2 = AxisHeight * (1 - \cos(\alpha))$$

$$h4 = AxisHeight + (WindowHeight - AxisHeight) * \cos(\alpha)$$

When z < h2 or z > h4, where z is the distance from the bottom of the window, the integration procedure is the same as the procedure for a normal rectangular window. When h2<z<h4, the window width W in the above equations is modified as:

$$W_{pivot} = \sqrt{\frac{1}{\frac{1}{W^2} + \frac{1}{(2*(AxisHeight - z)*\tan(\alpha))^2}}}$$

The mass flow rate in the pivoted area becomes:

$$\dot{m}_{pivot} = C_d \theta \int_{z=h2}^{z=h4} \rho v(z) W_{pivot} dz$$

It should be pointed out that the discharge coefficient is modulated based on opening factors, while opening width, opening height, and start height factor do not apply for a horizontally pivoted window. The actual window width and height are used to calculate airflows for a horizontally pivoted window.

The schematic drawing of air flow patterns through a vertical opening (AirflowNetwork:Multizone:Component Simple Opening) is shown in Figure 20. The equations used below are available in Walton, 1989.

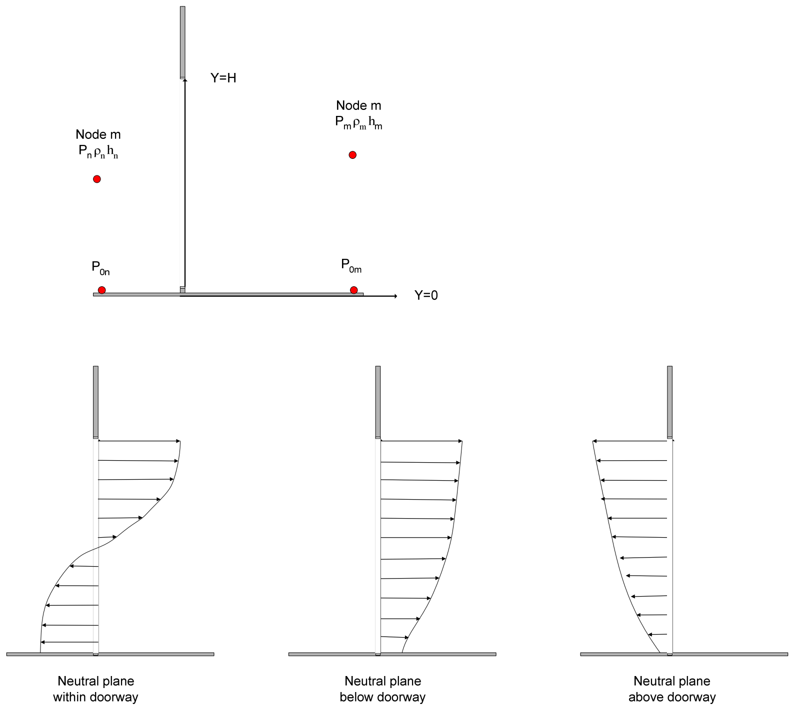


Figure 20. Schematic of large opening and associated three flow patterns

The air density of each node is assumed to be constant. The hydrostatic equation is used to relate pressures at various heights in each node:

$$P_n(y) = P_{0n} - \rho_n g y$$

$$P_m(y) = P_{0m} - \rho_m g y$$

where

P_{0n}, P_{0m} = pressure in nodes (zones) n and m at y = 0, the reference elevation of the opening,

ρ_n, ρ_m = air densities of zones n and m

P_n, P_m = reference pressures of zones n and m.

In the following [Brown and Solvason 1962], it is assumed that the velocity of the airflow as a function of height is given by the orifice equation:

$$v(y) = C_d \sqrt{2 \frac{P_n(y) - P_m(y)}{\rho}}$$

where

C_d = discharge coefficient, and

ρ = density of the air going through the opening.

The neutral height, Y, where the velocity of the air is zero, may be calculated in the following equation:

$$Y = \frac{P_{on} - P_{0m}}{g(\rho_n - \rho_m)} \quad or \quad \frac{P_{om} - P_{0n}}{g(\rho_m - \rho_n)}$$

When the neutral plane is within the opening (first pattern in Figure 20), two way (bi-directional) flows occur. The total flow through a large opening is the sum of both flows.

$$\dot{m}_{0,Y} = C_d \theta \int_{y=0}^{y=Y} \rho v(y) W dy$$

$$\dot{m}_{Y,H} = C_d \theta \int_{y=Y}^{y=H} \rho v(y) W dy$$

When the neutral plane is below or above the large opening (Second and third pattern in Figure 20), one way flow occurs.

$$\dot{m} = C_d \theta \int_{y=0}^{y=H} \rho v(y) W dy$$

The opening width is modulated based on opening factors. A detailed description of opening factor calculations may be found in the Input Output Reference (Ref. AirflowNetwork:Multizone:Zone, AirflowNetwork:Multizone:Surface, and AirflowNetwork:Multizone:Component Detailed Opening).

Wind pressure calculations

The wind pressure is determined by Bernoulli's equation, assuming no height change or pressure losses:

$$p_w = C_p \rho \frac{V_{ref}^{\ 2}}{2}$$

where

p_w = Wind surface pressure relative to static pressure in undisturbed flow [Pa]

ρ = Air density [kg/m^3]

V_{ref} = Reference wind speed at local height [m/s]

C_p = Wind surface pressure coefficient [dimensionless]

V_{ref} may be expressed as

$$V_{ref} = V * \left(\frac{Z_{bound}}{Z_{met}}\right)^{\alpha_{met}} * \left(\frac{Z_{ref}}{Z_{bound}}\right)^{\alpha}$$

where

V = Wind speed measured at weather station [m/s]

Z_{bound} = Boundary layer height [m]

Z_{met} = Meteorological station height for recorded wind data [m]

Z_{ref} = Reference height used for wind pressure coefficient data [m]

α_{met} = Wind velocity profile exponent at a meteorological station [dimensionless]

α = Wind velocity profile exponent at given side wind conditions [dimensionless]

C_p is a function of location on the building envelope and wind direction. When Wind Pressure Coefficient Type = "INPUT", the C_p values are explicitly defined in the input for AirflowNetwork:Multizone:Wind Pressure Coefficient Values. When Wind Pressure Coefficient Type = "AVERAGE-SURFACE CALCULATION" and the building shape is rectangular, the program uses the following equations to calculate wind pressure coefficient (C_p) values at different wind directions. For a low rise building, the normalized surface pressure coefficient may be written as (Swami and Chandra, 1988):

$$C_{p,n} = 0.6 * \ln \begin{bmatrix} 1.248 - 0.703\sin(\alpha/2) - 1.175\sin^2(\alpha) + 0.131\sin^3(2\alpha G) \\ +0.769\cos(\alpha/2) + 0.07G^2\sin^2(\alpha/2) + 0.717\cos^2(\alpha/2) \end{bmatrix}$$

where

$C_{p,n}$ = C_p value at a given angel between wind direction and the outward normal of the surface under consideration [dimensionless]

α = Angle between wind direction and outward normal of wall under consideration [deg]

G = Natural log of ratio of width of wall under consideration to width of adjacent wall [dimensionless]

n = Index of incident angle at 30 degree increments

For walls in a high rise building, a two dimensional array of surface-averaged wind pressure coefficients is generated based on wind incident angle and side ratio. The wind pressure coefficients are provided in 2001 ASHRAE Fundamentals Handbook, p. 16.5, Fig. 7, "Surface Averaged Wall Pressure Coefficients for Tall Buildings". The original work was performed by Atkins et al, 1979. The incident angle has an increment of 30 degrees. The side ratio values are 0.25, 1.0, and 4.0. For a given incident angle and building aspect ratio, the program uses linear interpolation to calculate the corresponding wind pressure coefficient: $C_{p,n}$.

For roofs in a high rise building, a two dimensional array of surface-averaged wind pressure coefficients is also generated based on wind incident angle and side ratio. The wind pressure coefficients are provided in 2001 ASHRAE Fundamentals Handbook, p. 16.6, Fig. 9, "Surface Averaged Roof Pressure Coefficients for Tall Buildings". The original work was performed by Holmes, 1986. The incident angle has an increment of 30 degrees. The side ratio values are 0.25, 1.0, and 4.0. At a given wind incident angle and building aspect ratio, the program uses linear interpolation to calculate the corresponding wind pressure coefficient: $C_{p,n}$.

The wind surface pressure at the given incident angle can be calculated by combining the above two equations:

$$p_{w,n} = C_{p,n}\rho\frac{V_{ref}^{\ 2}}{2}$$

Solution method

Based on the relationship between airflow rate and pressure drop for each component, a system of equations with all the components can be assembled together in an n x n square matrix, where n is the number of nodes. Newton's method is used to iteratively solve for the pressure at each node. A new estimated vector of all node pressures, {P}*, is computed from the current estimated vector of node pressures, {P}, by:

$$\{P\}^* = \{P\} - \{C\}$$

where the correction vector, {C}, is computed by the matrix relationship:

$$[J]\{C\} = \{B\}$$

{B} is a column vector with each component given by:

$$B_n = \sum_i \dot{m}_i$$

where n is the node number and i indicates all flow paths connecting node n to other nodes, and [J] is the square Jacobian matrix whose elements are given by:

$$J_{n,m} = \sum_i \frac{\partial \dot{m}}{\partial P_m}$$

Convergence acceleration

The convergence tolerance is used to check the sum of the mass flow rates by applying mass conservation. The convergence acceleration equation shown below is used to correct the node pressures in order to obtain a fast solution. By assuming a constant ratio, the following method is applied:

$$P_n^* = P_n - C_n/(1-r)$$

where

r = the ratio of C_n for the current iteration to its value for the previous iteration

C_n = Correction value at the n_{th} node

P_n = Estimated pressure at the n_{th} node

P_n^* = Corrected pressure at the n_{th} node used in the next iteration

This method is similar to a Steffensen iteration (Conte & de Boor, 1972) which is used with a fixed point iteration method for individual nonlinear equations.

The iteration correction method presented in the above equation gives a variable factor. When the solution is close to convergence, the solution method converges quadratically. By limiting cases where the value of r is less than some value, such as -0.5, the solution will not interfere with the rapid convergence. However, it has not been proven that the convergence acceleration equation will always lead to convergence, but it can be shown that it will not prevent convergence. The Newton's method converges when the estimated solution values are within some distance, called the radius of convergence, or the correct solution. Applying the convergence acceleration equation when -1 < r <0, will cause a smaller correction than Newton's method, which therefore, can not force the iterations outside the radius of convergence. When r<-1, the solution diverges in an oscillatory fashion. When r>1, the solution also diverges, but in a nonoscillatory manner. For 0<r<1, the solution is approached from one direction. In all three cases, the convergence acceleration equation applies as long as r is truly constant over several iterations. However, for the last case, this involves a true extrapolation of correction factor which is very sensitive to the accuracy of r. This is most extreme for the case of r=1, which would cause an infinite correction.

Node Temperature Calculations

A brief description of the node temperature calculation is given below. A detailed description can be found in the work of Swami et al. (1992). The following equation is used to calculate temperature distribution across a duct element at the given airflow rate and inlet temperature:

$$\dot{m} C_p \frac{dT}{dx} = UP(T_\infty - T)$$

where

C_p	= Specific heat of duct wall [J/kg.K]
$\dot{m}$	= Airflow rate [kg/s]
P	= Perimeter of a duct element [m]
T	= Temperature as a field variable [^oC]
T_∞	= Ambient temperature surrounding the duct element [^oC]
U	= Overall heat transfer coefficient [$W/m^2.K$]

$$U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o} + \sum \frac{t_j}{k_j}}$$

h_i	= Inside heat transfer coefficient [$W/m^2.K$]
h_o	= Outside heat transfer coefficient [$W/m^2.K$]
t_j	= Thickness at j-th layer [m]
k_j	= Thermal conductivity at j-th layer [W/m.K]

The outlet temperature at the end of the duct (x=L) is:

$$T_o = T_\infty + (T_i - T_\infty) * \exp\left(-\frac{UA}{\dot{m} C_p} \right)$$

where

T_i	= Inlet air temperature [^oC]
T_o	= Outlet air temperature [^oC]
T_∞	= Ambient air temperature [^oC]
A	= Surface area (Perimeter * Length) [m^2]

The heat transfer by convection to ambient, Q, is:

$$Q = \dot{m} C_p (T_\infty - T_i) \left[1 - \exp\left(-\frac{UA}{\dot{m} C_p} \right) \right]$$

The outlet node temperature can be calculated using the above equation at the given inlet temperature. Since the inlet temperature at one linkage is the outlet temperature for the connected linkage, the outlet temperatures at all nodes are solved simultaneously. A square linear system assembled by the AirflowNetwork model is expressed below:

$$\{M\}[T]=[B]$$

where

{M}	= Airflow matrix
[T]	= Temperature vector
[B]	= Given boundary conditions

The zone temperatures and primary air loop component (fan and coils) outlet conditions are used as prescribed conditions in the AirflowNetwork model. In addition, the temperature difference of zone loop components (terminal units) is held constant during the calculations. For example, thermal zone temperatures calculated during the previous system time step are used as prescribed temperatures when calculating all other node temperatures. The zone temperature is assumed constant (prescribed) throughout the AirflowNetwork iterative solution. The fan and coil outlet temperatures, and terminal unit temperature differences are assumed constant within an AirflowNetwork iteration. The sensible heat gains calculated during the AirflowNetwork solution are then used to predict a new zone temperature.

Node Humidity Ratio Calculations

A brief description of the node humidity ratio calculation is given below. A detailed description can found in the work of Swami et al. (1992). The following equation is used to calculate humidity ratio distribution across a duct element at the given airflow rate and inlet humidity ratio:

$$\dot{m}\frac{dW}{dx}=U_m P(W_\infty - W)$$

where

$\dot{m}$	= Airflow rate [kg/s]
P	= Perimeter of a duct element
W	= Humidity ratio [kg/kg]
W_∞	= Ambient humidity ratio [kg/kg]
U_m	= Overall moisture transfer coefficient [kg/m^2-s]

$$U_m=\frac{1}{\frac{1}{h_{m,i}}+\frac{1}{h_{m,o}}+\sum\frac{t_j}{D_j}}$$

$h_{m,i}$	= Inside moisture transfer coefficient [kg/m^2-s]
$h_{m,o}$	= Outside moisture transfer coefficient [kg/m^2-s]
t_j	= Thickness at j-th layer [m]
D_j	= Moisture diffusivity at j-th layer [kg/m-s]

The outlet humidity ratio at the end of the duct (x=L) is:

$$W_o = W_\infty + (W_i - W_\infty) * \exp\left(-\frac{U_m A}{\dot{m}} \right)$$

where

W_i = Inlet air humidity ratio [kg/kg]

W_o = Outlet air humidity ratio [kg/kg]

A = Surface area = PL [m^2]

The moisture transfer by convection to ambient, Q_m, is

$$Q_m = \dot{m}(W_\infty - W_i)\left[1 - \exp\left(-\frac{U_m A}{\dot{m}} \right)\right]$$

The outlet node humidity ratio can be calculated using the above equation at the given inlet humidity ratio. Since the inlet humidity ratio at one linkage is the outlet humidity ratio for the connected linkage, the outlet humidity ratio at all nodes are solved simultaneously. A square linear system assembled by the AirflowNetwork model is expressed below:

$$\{M_m\}[W] = [B_m]$$

where

$\{M_m\}$ = Airflow matrix

[W] = Humidity ratio vector

$[B_m]$ = Given boundary conditions

The zone humidity ratios and primary air loop component (fan and coils) outlet conditions are used as prescribed conditions in the AirflowNetwork model. For example, thermal zone humidity ratios calculated during the previous system time step are used as prescribed humidity ratios when calculating all other node humidity ratios. The zone humidity ratio is assumed constant (prescribed) throughout the AirflowNetwork iterative solution. The coil outlet humidity ratio is assumed constant within an AirflowNetwork iteration. The latent heat gains calculated during the AirflowNetwork solution are then used to predict a new zone humidity ratio.

Sensible and latent load calculations

The zone sensible and latent loads calculated in the AirflowNetwork model consist of multizone duct conduction and leakage. In addition, the impact of infiltration and mixing is accounted for in this calculation. The multizone load only includes incoming airflows from outside (infiltration) and other adjacent zones (mixing) with and without force air fan operation. It is divided into two terms: variable and constant. The constant term is the sum of the mass flow rate multiplied by the specific heat for both infiltration and mixing. The variable term includes the impact of zone and outdoor temperature. Each of these terms are used in the zone energy balance equation. The sensible load items from multizone load calculations may be written as follows:

$$MCP_{airflow} = \dot{m}_{\inf} * C_p + \sum \dot{m}_{mix} * C_p$$

$$MCPT_{airflow} = \dot{m}_{\inf} * C_p T_{amb} + \sum \dot{m}_{mix} * C_p * T_{zone}$$

where

MCP$_{airflow}$ = Sum of mass flow rate multiplied by specific heat for infiltration and mixing [W/K]

MCPT$_{airflow}$ = Sum of mass flow rate multiplied by specific heat and temperature for infiltration and mixing [W]

$\dot{m}_{\inf}$ = Incoming mass flow rate from outdoors [kg/s]

$\dot{m}_{mix}$ = Incoming mass flow rate from adjacent zones [kg/s]

T_{amb} = Outdoor dry bulb temperature

T_{zone} = Adjacent zone air temperature

The latent load items from multizone load calculations may be written as follows:

$$M_{airflow} = \dot{m}_{\inf} + \sum \dot{m}_{mix}$$

$$MW_{airflow} = \dot{m}_{\inf} * W_{amb} + \sum \dot{m}_{mix} * W_{zone}$$

where

M$_{airflow}$ = Sum of mass flow rates for infiltration and mixing [kg/s]

MW$_{airflow}$ = Sum of mass flow rate multiplied by humidity ratio for infiltration and mixing [kg/s]

$\dot{m}_{\inf}$ = Incoming mass flow rate from outdoors [kg/s]

$\dot{m}_{mix}$ = Incoming mass flow rate from adjacent zones [kg/s]

W_{amb} = Outdoor humidity ratio

W_{zone} = Adjacent zone air humidity ratio

The air distribution system loads due to duct conduction and leakage depend on the air distribution system component (e.g., ducts) location. The air distribution system sensible and latent loads are calculated for each zone as follows:

$$Q_{ADS,i} = \sum_j Q_{cond(i,j)} + \sum_j Q_{leak(i,j)}$$

$$Q_{ADS,m,i} = \sum_j Q_{cond,m(i,j)} + \sum_j Q_{leak,m(i,j)}$$

where

$Q_{ADS,i}$ = Total sensible load in the i-th zone due to ADS losses [W]

$Q_{cond(ij)}$ = Duct wall conduction loss at the j-th duct located in the i-th zone [W]

$Q_{leak(ij)}$ = Sensible supply leak loss at the j-th linkage located in the i-th zone [W]

$Q_{ADS,m,i}$ = Total latent load in the i-th zone due to ADS losses [kg/s]

$Q_{cond,m(ij)}$ = Duct wall vapor diffusion loss at the j-th duct located in the i-th zone [kg/s]

$Q_{leak,m(ij)}$ = Latent supply leak loss at the j-th linkage located in the i-th zone [kg/s]

Integration of the AirflowNetwork Model

The loads calculated by the AirflowNetwork model are integrated into the EnergyPlus heat balance equation in a similar manner as described elsewhere in this document in the section "Basis for the Zone and System Integration". The mass flow rate summations and sensible and latent loads described in the previous section are included in the calculation of zone temperature and humidity ratio.

The revised zone temperature update equation becomes:

$$T_z^t = \frac{\sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i T_{si} + MCPT_{airflow} + \dot{m}_{sys} C_p T_{supply} + Q_{ADS,z} - \left(\frac{C_z}{\delta t}\right)\left(-3T_z^{t-\delta t} + \frac{3}{2}T_z^{t-2\delta t} - \frac{1}{3}T_z^{t-3\delta t}\right)}{\left(\frac{6}{11}\right)\frac{C_z}{\delta t} + \sum_{i=1}^{N_{surfaces}} h_i A_i + MCP_{airflow} + \dot{m}_{sys} C_p}$$

where $Q_{ADS,z}$ is the added total sensible load in the zone due to Air Distribution System losses calculated in the AirflowNetwork model.

The revised coefficient (B) used in the zone humidity ratio calculation is shown below:

$$B = \sum kg_{mass_{sched,loads}} + MW_{airflow} + \dot{m}_{sys_{in}} W_{sys} + \sum_{i=1}^{surfs} A_i h_{mi} \rho_{air} W_{surfs_i} + Q_{ADS,m,z}$$

where $Q_{ADS,m,z}$ is the added total latent (moisture) load in the zone due to Air Distribution System losses from the AirflowNetwork model. This coefficient is used in the prediction of moisture as described in the section "Moisture Predictor-Corrector" found elsewhere in this document.

Model Output

The available outputs from the AirflowNetwork model are described in the EnergyPlus Input Output Reference manual.

References

Atkins, R. E., J. A. Peterka, and J. E. Cermak, 1979, "Averaged pressure coefficients for rectangular buildings," Wind Engineering, Proceedings of the Fifth International Conference 7:369-80, Fort Collins, CO. Pergamon Press, NY.

COMIS Fundamentals, 1990, Edited by Helmut E. Feustel and Alison Rayner-Hooson, LBL-28560, Lawrence Berkeley Laboratory, Berkeley, CA

Conte, S. D. & de Boor, C., 1972, Elementary Numerical Analysis: an Algorithmic Approach, McGraw-Hill.

Dols, W. S. & G. N. Walton, 2002, "CONTAMW 2.0 User Manual," NISTIR 6921, National Institute of Standards and Technology, Gaithersburg, Maryland

Holmes, J. D. 1986, Wind Loads on low-rise buildings: The structural and environmental effects of wind on buildings and structures, Chapter 12, Faculty of Engineering, Monash University, Melbourne, Australia

Swami, M. V. and S. Chandra. 1988. Correlation for pressure distribution on buildings and calculation of natural-ventilation airflow. ASHRAE Transactions 81(1):202

Swami, M. V., L. Gu, & V. Vasanth, 1992, "Integration of Radon and Energy Models for Building," FSEC-CR-553-92, Florida Solar Energy Center, Cocoa, Florida

Walton, G. N. 1989, "AIRNET – A Computer Program for Building Airflow Network Modeling," NISTIR 89-4072, National Institute of Standards and Technology, Gaithersburg, Maryland

Walton, G. N. & W. S. Dols, 2003, "CONTAM 2.1 Supplemental User Guide and Program Documentation," NISTIR 7049, National Institute of Standards and Technology, Gaithersburg, Maryland

Appendix E

EnergyPlus Documentation for Modeling Comfort-Based Controls for Cooling and Heating Systems

This appendix contains the EnergyPlus documentation (Input/Output Reference and Engineering Manual) that describes the comfort-based controls for cooling and heating systems added as part of this project.

Input Output Reference for Zone Control:Thermal Comfort

The Zone Control:Thermal Comfort object provides a method to control a zone to a dry-bulb temperature setpoint based on a thermal comfort model (e.g. Fanger) and a user-specified thermal comfort setpoint schedule.

This object references a control type schedule and one or more thermal comfort control type objects which in turn reference one or more setpoint schedules. The example at the end of this section illustrates a complete zone thermal comfort control specification including the control type and setpoint schedules. The control type schedule and the list of control type/name pairs are directly related. The schedule defines the type of control that is to be used during for each hour. Valid Control Types are:

0 - Uncontrolled (No thermal comfort control)

1 - Single Thermal Comfort Heating Setpoint:Fanger

2 - Single Thermal Comfort Cooling Setpoint:Fanger

3 - Single Thermal Comfort Heating Cooling Setpoint:Fanger

4 - Dual Thermal Comfort Setpoint with Deadband:Fanger

Thus, if the schedule referenced in the ZONE CONTROL statement has a value of 4 for a particular hour, this indicates that during that hour "Dual Thermal Comfort Setpoint with Deadband:Fanger" is to be used. The specific "Dual Thermal Comfort Setpoint with Deadband:Fanger " control object to be used is specified in the list of control type/name pairs. Then the specific control type objects reference the thermal comfort control setpoint schedule to be used. Because only one control can be specified for each control type in a ZONE CONTROL statement, there are only four pairs possible in a particular ZONE CONTROL type/name list. This is because individual controls can be defined hourly, thus giving the user a full range of flexibility. Since putting in the name of the control type directly in the schedule would be very cumbersome, the control types are assigned a number which is used in the hourly schedule profile.

The Zone Control:Thermal Comfort object can be used alone, or with a Zone Control:Thermostatic object. When both Zone Control:Thermostatic and Zone Control:Thermal Comfort objects co-exist for a specific zone and the thermal comfort control type value in the thermal comfort control type schedule is non-zero the thermal comfort object will override the value from the zone thermostat object. If the thermal comfort control is specified as “Uncontrolled” (thermal comfort control type value of 0) for a particular period, then control will revert to thermostat control if specified. If the thermal comfort control is specified as “Uncontrolled” for a particular period and thermostat control is not specified in the input, then conditions will float.

This object currently allows only Fanger comfort control (Ref. Thermal Comfort in Engineering Reference). It requires one or more people objects in a specific zone. It also requires inputs of Fields *Activity Level Schedule Name, Work Efficiency Schedule Name, Clothing Insulation Schedule Name* and *Air Velocity Schedule Name* in the people object(s). When thermal comfort control is used in a zone, the air velocity entered in the Air Velocity Schedule (Ref. People) should be greater than or equal to 0.1 and less than or equal to 0.5 m/s. A warning message will be issued if thermal comfort control is active and the air velocity is outside this range.

This object reads input PMV values from a given PMV setpoint schedule to calculate a dry-bulb temperature setpoint based on the selected thermal comfort model. The dry-bulb temperature setpoint calculation uses zone air humidity ratio at the previous system time step and surface temperatures at the previous zone time step, along with other conditions at the current time step (e.g., activity level, clothing level and air velocity from the PEOPLE object).

Field: Thermal Comfort Control Name

Unique identifying name for this thermal comfort control object.

Field: Zone Name

Name of the zone that is being controlled.

Field: Averaging Method for Zones With Multiple People Objects

This choice field specifies the method for calculating the thermal comfort dry-bulb temperature setpoint for a zone with multiple PEOPLE objects defined. The available choices are: Specific object, Object Average, and People Average. This field is only used when multiple people objects are defined for this zone. If this field is specified as People Average and the total number of people for all people objects is zero for a particular time step, the People Average method can not be applied and the program automatically uses the Object Average method for this time step. The default input is People Average.

Field: Object Name for Specific Object Averaging Method

This choice field specifies the name of the specific PEOPLE object to be used for calculating comfort control when multiple PEOPLE objects are defined. Only used if the Averaging Method for Zones With Multiple People Objects is specified as "Specific Object."

Field: Minimum Dry-bulb Temperature Set Point

This field specifies the minimum dry-bulb temperature setpoint allowed for this zone. If the dry-bulb temperature calculated by the thermal comfort setpoint model is below this value, then the temperature setpoint will be set to this value. The default value is 0 ˚C.

Field: Maximum Dry-bulb Temperature Set Point

This field specifies the maximum dry-bulb temperature setpoint allowed for this zone. If the dry-bulb temperature calculated by the thermal comfort setpoint model exceeds this value, then the temperature setpoint will be set to this value. The default value is 50 ˚C.

Note the minimum and maximum temperature setpoint fields are provided to allow the user to bound the temperature control In a specific zone if necessary. These fields are used to provide boundaries for the dry-bulb temperature setpoint calculated at each system time step when unrealistic inputs have been specified.

Field: Thermal Comfort Control Type SCHEDULE Name

Schedule which defines what type of thermal comfort control is active during each simulation time step.

Valid Control Types are:

- 0 - No thermal comfort control
- 1 - Single Thermal Comfort Heating Setpoint:Fanger
- 2 - Single Thermal Comfort Cooling Setpoint:Fanger
- 3 - Single Thermal Comfort Heating Cooling Setpoint:Fanger
- 4 - Dual Thermal Comfort Setpoint with Deadband:Fanger

Each non-zero control type used in this schedule must appear in the following fields which list the specific thermal comfort control objects to be used for this zone.

Field Set (Thermal Comfort Control Type, Thermal Comfort Control Type Name)

Up to four pairs of Thermal Comfort Control Type and Thermal Comfort Control Type Name fields may be listed to specify which thermal comfort control type objects are used for this zone. This list is not order-dependent, and the position in this list has no impact on the control type schedule. In the control type schedule, a value of 1 always means "Single Thermal Comfort Heating Setpoint:Fanger", even if that control type is not first in this list.

Field: Thermal Comfort Control Type

This field specifies the first control type name to be used for this zone. Available control types are:

Single Thermal Comfort Heating Setpoint:Fanger

Single Thermal Comfort Cooling SetPoint:Fanger

Single Thermal Comfort Heating Cooling Setpoint:Fanger

Dual Thermal Comfort Setpoint with Deadband:Fanger

Field: Thermal Comfort Control Type Name

The unique name for the corresponding thermal comfort control type.

The input data dictionary description for the thermal comfort object is shown below:

```
ZONE CONTROL:THERMAL COMFORT,
       \min-fields 9
  A1 , \field Thermal Comfort Control Name
       \required-field
       \reference ZoneControlThermalComfortNames
  A2 , \field Zone Name
       \required-field
       \type object-list
       \object-list ZoneNames
  A3 , \field Averaging Method for Zones with Multiple People Objects
       \note The method used to calculate thermal comfort dry-bulb temperature setpoint
       \note for multiple people objects in a zone
       \type choice
       \key Specific Object
       \key Object Average
       \key People Average
       \default People Average
  A4 , \field Object Name for Specific Object Averaging Method
       \note Used only for Specific Object Average Method input in the previous field.
       \type object-list
       \object-list PeopleNames
  N1 , \field Minimum dry-bulb temperature setpoint
       \required-field
       \type real
       \units C
       \minimum 0
       \maximum 50
       \default 0
  N2 , \field Maximum dry-bulb temperature setpoint
       \required-field
       \type real
       \units C
       \minimum 0
       \maximum 50
       \default 50
  A5 , \field Thermal Comfort Control Type SCHEDULE Name
       \note The Thermal Comfort Control Type Schedule contains appropriate control types.
       \note Thermal Comfort Control types are integers: 0 - uncontrolled (floating),
       \note 1 = Single Thermal Comfort Heating Setpoint:Fanger
       \note 2 = Single Thermal Comfort Cooling Setpoint:Fanger
       \note 3 = Single Thermal Comfort Heating Cooling Setpoint:Fanger
       \note 4 = Dual Thermal Comfort Setpoint with Deadband:Fanger
       \required-field
       \type object-list
       \object-list ScheduleNames
  A6 , \field Thermal Comfort Control Type #1
       \required-field
       \type choice
       \key Single Thermal Comfort Heating Setpoint:Fanger
       \key Single Thermal Comfort Cooling SetPoint:Fanger
       \key Single Thermal Comfort Heating Cooling Setpoint:Fanger
       \key Dual Thermal Comfort Setpoint with Deadband:Fanger
  A7 , \field Thermal Comfort Control Type Name #1
       \note Control Type names are names for individual Control Type objects.
       \note Schedules in these objects list actual setpoint temperatures for the control types
       \required-field
       \type object-list
       \object-list ThermalComfortControlTypeNames
  A8 , \field Thermal Comfort Control Type #2
       \type choice
       \key Single Thermal Comfort Heating Setpoint:Fanger
       \key Single Thermal Comfort Cooling SetPoint:Fanger
       \key Single Thermal Comfort Heating Cooling Setpoint:Fanger
       \key Dual Thermal Comfort Setpoint with Deadband:Fanger
  A9 , \field Thermal Comfort Control Type Name #2
       \note Control Type names are names for individual Control Type objects.
       \note Schedules in these objects list actual setpoint temperatures for the control types
       \type object-list
       \object-list ThermalComfortControlTypeNames
  A10, \field Thermal Comfort Control Type #3
       \type choice
       \key Single Thermal Comfort Heating Setpoint:Fanger
       \key Single Thermal Comfort Cooling SetPoint:Fanger
       \key Single Thermal Comfort Heating Cooling Setpoint:Fanger
       \key Dual Thermal Comfort Setpoint with Deadband:Fanger
```

```
A11, \field Thermal Comfort Control Type Name #3
     \note Control Type names are names for individual Control Type objects.
     \note Schedules in these objects list actual setpoint temperatures for the control types
     \type object-list
     \object-list ThermalComfortControlTypeNames
A12, \field Thermal Comfort Control Type #4
     \type choice
     \key Single Thermal Comfort Heating Setpoint:Fanger
     \key Single Thermal Comfort Cooling SetPoint:Fanger
     \key Single Thermal Comfort Heating Cooling Setpoint:Fanger
     \key Dual Thermal Comfort Setpoint with Deadband:Fanger
A13; \field Thermal Comfort Control Type Name #4
     \note Control Type names are names for individual Control Type objects.
     \note Schedules in these objects list actual setpoint temperatures for the control types
     \type object-list
     \object-list ThermalComfortControlTypeNames
```

An example of this statement in an IDF is:

```
ZONE CONTROL:THERMAL COMFORT,
  Zone 2 Comfort Control,          !- Thermal Comfort Control Name
  EAST ZONE,                       !- Zone Name
  Specific Object,                 !- Averaging Method for Zones with Multiple People Objects
  EAST ZONE,                       !- Object Name for Specific Object Averaging Method
  12.8,                            !- Minimum dry-bulb temperature setpoint
  40.0,                            !- Maximum dry-bulb temperature setpoint
  Zone Comfort Control Type Sched, !- Thermal Comfort Control Type SCHEDULE Name
  Dual Thermal Comfort Setpoint WITH DEADBAND:Fanger, !- Control Type #1
  Dual Comfort Setpoint;           !- Thermal Comfort Control Type Name #1
```

Zone Control:Thermal Comfort Outputs

Three outputs are available from the Zone Control:Thermal Comfort object. Two report variables used primarily for the Zone Control:Thermostatic object are also described here to explain their meaning when using thermal comfort control.

```
ZONE CONTROL:THERMAL COMFORT
Zone,Average,Zone/Sys Thermal Comfort Control Type
Zone,Average,Zone/Sys Thermal Comfort Control Fanger Low PMV
Zone,Average,Zone/Sys Thermal Comfort Control Fanger High PMV

ZONE CONTROL:THERMOSTATIC
Zone,Average,Zone/Sys Thermostat Heating Setpoint [C]
Zone,Average,Zone/Sys Thermostat Cooling Setpoint [C]
```

Zone/Sys Thermal Comfort Control Type

This is the current zone thermal comfort control type (0 through 4). This value is set at each system time step and averaged over the reporting interval. Using the averaged value for longer reporting frequencies (hourly, for example) may not be meaningful in some applications.

Zone/Sys Thermal Comfort Control Fanger Low PMV

This is the current zone thermal comfort low PMV value. Values range between -3 and +3. If there is no heating thermal comfort active, then the value reported will be -999. This value is set at each system time step and averaged over the reporting interval. Using the averaged value for longer reporting frequencies (hourly, for example) may not be meaningful in some applications.

Zone/Sys Thermal Comfort Control Fanger High PMV

This is the current zone thermal comfort high PMV value. Values range between -3 and +3. If there is no cooling thermal comfort active, then the value reported will be 999. This value is set at each system time step and averaged over the reporting interval. Using the averaged value for longer reporting frequencies (hourly, for example) may not be meaningful in some applications.

Zone/Sys Thermostat Heating Setpoint [C]

The Zone Control:Thermal Comfort object shares the same output variable and overwrites the thermal setpoints defined in object Zone Control:Thermostatic when both objects of Zone Control:Thermostatic and Zone Control:Thermal Comfort co-exist. It outputs the current zone thermal comfort heating setpoint in degrees C when thermal comfort control is active, otherwise this output variable will report the thermostat heating setpoint (Ref. Zone Control:Thermostatic Outputs). If there is no heating thermal comfort active and no thermostat heating setpoint is defined for this zone, this value will be 0. This value is set at each system time step and averaged over the reporting interval. Using the averaged value for longer reporting frequencies (hourly, for example) may not be meaningful in some applications.

Zone/Sys Thermostat Cooling Setpoint [C]

This output variable defined in object Zone Control:Thermostatic. The Thermal Comfort object shares the same output variable and overwrites the thermal setpoints defined in object Zone Control:Thermostatic when both objects of Zone Control:Thermostatic and Zone Control:Thermal Comfort co-exist. It outputs the current zone thermal comfort cooling setpoint in degrees C when thermal comfort control is active, otherwise this output variable will report the thermostat cooling setpoint (Ref. Zone Control:Thermostatic Outputs). If there is no cooling thermal comfort active and no thermostat cooling setpoint is defined for this zone, this value will be 0. This value is set at each system time step and averaged over the reporting interval. Using the averaged value for longer reporting frequencies (hourly, for example) may not be meaningful in some applications.

Engineering Document for Zone Control:Thermal Comfort

The Zone Control (object name: Zone Control:Thermal Comfort) is a way for the zone to be controlled to a specified temperature based on a selected thermal comfort model. Zone Control:Thermal Comfort references a thermal comfort control type schedule and one or more thermal comfort control type objects which in turn reference one or more setpoint schedules.

The thermal comfort control type schedule and the list of thermal comfort control type/name pairs are directly related. The schedule defines the type of thermal comfort control that is to be used during for each simulation time step. Valid Control Types are

0 – No thermal comfort control

1 - Single Thermal Comfort Heating Setpoint:Fanger

2 - Single Thermal Comfort Cooling SetPoint:Fanger

3 - Single Thermal Comfort Heating/Cooling Setpoint:Fanger

4 - Dual Thermal Comfort Setpoint with Deadband:Fanger

If the schedule referenced in the ZONE CONTROL statement has a value of 4 for a particular time step, this indicates that during that time step "Dual Thermal Comfort Setpoint with Deadband:Fanger" control is to be used. The specific "Dual Thermal Comfort Setpoint with Deadband:Fanger" control object to be used is specified in the list of thermal comfort control type/name pairs. Then the specific thermal comfort control type objects reference the thermal comfort PMV setpoint schedule to be used. Because only one thermal comfort control can be specified for each thermal comfort control type in a ZONE CONTROL statement, there are only four pairs possible in a particular ZONE CONTROL type/name list. This is because individual thermal comfort controls can be defined for specific times, thus giving the user a full range of flexibility. Since putting in the name of the thermal comfort control type directly in the schedule would be very cumbersome, the thermal comfort control types are assigned a number which is used in the schedule profile.

For more information see Zone Control:Thermal Comfort in the InputOutput Reference and Zone Fanger Thermal Comfort in the Engineering Documentation.

Input Output Reference for Zone Fanger Thermal Comfort

The syntax for the current set (4) of zone thermal comfort control types is given below. In each case, the keyword is accompanied by an identifying name and either one or two schedule names (depending on whether the control type is a single or dual setpoint control). The schedule defines a PMV setpoint for the control type. The schedule would be defined through the standard schedule syntax described earlier in this document. For an uncontrolled thermal comfort zone, no Fanger thermal comfort object is specified or necessary.

Single Thermal Comfort Heating Setpoint:Fanger

This would be used for heating only thermal comfort control. The PMV setpoint can be scheduled and varied throughout the simulation but only heating is allowed with this control type.

Field: Name

Unique name for this control type.

Field: Fanger Thermal Comfort PMV SCHEDULE Name

The name of the associated schedule containing FANGER PMV values.

Single Thermal Comfort Cooling Setpoint:Fanger

This would be used for cooling only thermal comfort control. The PMV setpoint can be scheduled and varied throughout the simulation but only cooling is allowed with this control type.

Field: Name

Unique name for this control type.

Field: Fanger Thermal Comfort PMV SCHEDULE Name

The name of the associated schedule, containing FANGER PMV values.

Single Thermal Comfort Heating Cooling Setpoint:Fanger

This would be used for heating and cooling thermal comfort control but only heating or cooling can be scheduled at any given time period. The PMV setpoint can be scheduled and varied throughout the simulation for both heating and cooling.

Field: Name

Unique name for this control type.

Field: Fanger Thermal Comfort PMV SCHEDULE Name

The name of the associated schedule containing FANGER PMV values.

Dual Thermal Comfort Setpoint with Deadband:Fanger

This would be used for heating and cooling thermal comfort control where both a heating and cooling PMV setpoint can be scheduled for any given time period. The PMV setpoint can be scheduled and varied throughout the simulation for both heating and cooling.

Field: Name

Unique name for this control type.

Field: Fanger Thermal Comfort Heating Setpoint PMV SCHEDULE Name

The name of the associated schedule containing heating setpoint FANGER PMV values.

Field: Fanger Thermal Comfort Cooling Setpoint PMV SCHEDULE Name

The name of the associated schedule containing cooling setpoint FANGER PMV values.

The input data dictionary description for the thermal comfort control objects is shown below:

```
SINGLE THERMAL COMFORT HEATING SETPOINT:FANGER,
       \min-fields 2
  A1 , \field Name
       \required-field
       \type alpha
       \reference ThermalComfortControlTypeNames
  A2 ; \field FANGER Thermal Comfort PMV SCHEDULE Name
       \required-field
       \type object-list
       \object-list ScheduleNames

SINGLE THERMAL COMFORT COOLING SETPOINT:FANGER,
       \min-fields 2
  A1 , \field Name
       \required-field
       \type alpha
       \reference ThermalComfortControlTypeNames
  A2 ; \field FANGER Thermal Comfort PMV SCHEDULE Name
       \required-field
       \type object-list
       \object-list ScheduleNames

SINGLE THERMAL COMFORT HEATING COOLING SETPOINT:FANGER,
       \min-fields 2
  A1 , \field Name
       \required-field
       \type alpha
       \reference ThermalComfortControlTypeNames
  A2 ; \field FANGER Thermal Comfort PMV SCHEDULE Name
       \required-field
       \type object-list
       \object-list ScheduleNames

DUAL THERMAL COMFORT SETPOINT WITH DEADBAND:FANGER,
       \min-fields 3
  A1 , \field Name
       \required-field
       \type alpha
       \reference ThermalComfortControlTypeNames
  A2 , \field Fanger Thermal Comfort Heating Setpoint PMV SCHEDULE Name
       \required-field
       \type object-list
       \object-list ScheduleNames
  A3 ; \field Fanger Thermal Comfort Cooling Setpoint PMV SCHEDULE Name
       \required-field
       \type object-list
       \object-list ScheduleNames
```

An example of this statement in an IDF is:

```
SINGLE THERMAL COMFORT HEATING SETPOINT:FANGER,
  Heating Comfort Setpoint,!- Name
  Heating PMV Setpoints;   !- Setpoint Temperature SCHEDULE Name

SINGLE THERMAL COMFORT COOLING SETPOINT:FANGER,
  Cooling Comfort Setpoint,!- Name
  Cooling PMV Setpoints;   !- Setpoint Temperature SCHEDULE Name

SINGLE THERMAL COMFORT HEATING COOLING SETPOINT:FANGER,
  Heating Cooling Comfort Setpoint,!- Name
  Heating Cooling PMV Setpoints;   !- Setpoint Temperature SCHEDULE Name

DUAL THERMAL COMFORT SETPOINT WITH DEADBAND:FANGER,
  Dual Comfort Setpoint,   !- Name
  Heating PMV Setpoints,   !- Fanger Thermal Comfort Heating Setpoint PMV SCHEDULE Name
  Cooling PMV Setpoints;   !- Fanger Thermal Comfort Cooling Setpoint PMV SCHEDULE Name
```

Engineering Document for Zone Fanger Thermal Comfort

The syntax for the current set (4) of zone thermal comfort control types is given below. In each case, the keyword is accompanied by an identifying name and either one or two schedule names (depending on whether the control type is a single or dual setpoint control). The schedule defines a PMV setpoint for the control type. The schedule would be defined through the standard schedule syntax described earlier in this document. For an uncontrolled thermal comfort zone, no Fanger thermal comfort object is specified or necessary. See the Input Output Reference for more details.

The control type schedule and the list of control type/name pairs are directly related. The schedule defines the type of control that is to be used during for each hour. Valid Control Types are:

0 - No thermal comfort control

1 - Single Thermal Comfort Heating Setpoint:Fanger

2 - Single Thermal Comfort Cooling Setpoint:Fanger

3 - Single Thermal Comfort Heating Cooling Setpoint:Fanger

4 - Dual Thermal Comfort Setpoint with Deadband:Fanger

For the no thermal comfort control (uncontrolled) case, the control will revert to thermostat control if specified. If the thermal comfort control is specified as “uncontrolled” for a particular period and thermostat control is not specified in the input, then conditions will float.

For the Single Thermal Comfort Heating Setpoint:Fanger there would be a heating only thermal comfort set point temperature. The setpoint is calculated based on the selected thermal comfort model and varied throughout the simulation but only heating is allowed with this thermal comfort control type.

```
CASE (Single Thermal Comfort Heating Setpoint:Fanger)
TempControlType(ZoneNum)= SingleHeatingSetpoint
TempZoneThermostatSetPoint(ZoneNum) = Calculated Zone Setpoint from Fanger heating setpoint PMV
```

For the Single Thermal Comfort Cooling Setpoint:Fanger there would be a cooling only thermal comfort set point temperature. The setpoint is calculated based on the selected thermal comfort model and varied throughout the simulation but only cooling is allowed with this thermal comfort control type.

```
CASE (Single Thermal Comfort Cooling Setpoint:Fanger)

TempControlType(ZoneNum)= SingleCoolingSetPoint
TempZoneThermostatSetPoint(ZoneNum) = Calculated Zone Setpoint from Fanger cooling setpoint PMV
```

For the Single Thermal Comfort Heating Cooling Setpoint:Fanger there would be heating and cooling thermal comfort zone control objects. The setpoint is calculated based on the selected thermal comfort model and varied throughout the simulation for both heating and cooling. With this thermal comfort control type only 1 setpoint profile is needed or used.

```
CASE (Single Thermal Comfort Heating Cooling Setpoint:Fanger)

TempControlType(ZoneNum)= SingleHeatCoolSetPoint
TempZoneThermostatSetPoint(ZoneNum) = Calculated Zone Setpoint from Fanger heating and cooling
                                      setpoint PMV
```

For Dual Thermal Comfort Setpoint with DeadBand:Fanger there would be heating and cooling thermal comfort control objects. For this case both a heating and cooling setpoint can be calculated based on the selected thermal comfort model for any given time period. The thermal comfort setpoint temperature can be varied throughout the simulation for both heating and cooling.

```
CASE (Dual Thermal Comfort Setpoint with Deadband:Fanger)

TempControlType(ZoneNum)= DualSetPointWithDeadBand
ZoneThermostatSetPointLo(ZoneNum) = Calculated Zone Setpoint from Fanger heating setpoint PMV
ZoneThermostatSetPointHi(ZoneNum) = Calculated Zone Setpoint from Fanger cooling setpoint PMV
```

Appendix F

EnergyPlus Documentation and Reference Data Sets for Modeling Microturbine Power Generation with Heat Recovery

This appendix contains the EnergyPlus documentation (Input/Output Reference and Engineering Manual) that describes the microturbine generator model added as part of this project. It also contains reference data sets of model inputs for microturbine generators which are distributed with EnergyPlus.

Input Output Reference for Generator:Microturbine

Microturbine generators are small combustion turbines that produce electricity on a relatively small scale (e.g., 25kW to 500kW). This model uses nominal performance at reference conditions along with several modifier curves to determine electrical power output and fuel use at non-reference conditions. Standby and ancillary power can also be taken into account. Furthermore, energy recovery from exhaust air can be used to heat water. Similar to electrical power output, thermal power (heat recovery) output is calculated using nominal performance at reference conditions with modifier curves to account for variations at non-reference conditions.

The following inputs define the microturbine electric generator. The Electric Load Center: Generators and Electric Load Center:Distribution objects are used to define the availability and control of all electric generators included in the simulation (ref. Electric Load Center:Generators and Electric Load Center:Distribution).

Field: Generator Name

This alpha field specifies a unique user-defined name to identify this generator. This is a required input.

Field: Reference Electrical Power Output

This numeric field specifies the full-load electrical power output of the microturbine generator in Watts at reference conditions. The reference conditions are defined via additional input fields for this object (see below). This is a required input, and the value entered in this field must be greater than zero.

Field: Minimum Full Load Electrical Power Output

This numeric field specifies the minimum electrical power output in Watts at full-load conditions. The electrical power output of the generator is determined by multiplying the Reference Electrical Power Output by the Electrical Power Modifier Curve (function of temperature and elevation). If the result is less than the numeric value specified in this input field, then the generator’s electrical power output is reset to the minimum full-load value specified in this input field. The value entered in this field must be greater than or equal to zero. If this field is left blank, the default value of 0.0 will be used.

Field: Maximum Full Load Elecrical Power Output

This numeric field specifies the maximum electrical power output in Watts at full-load conditions. The electrical power output of the generator is determined by multiplying the Reference Electrical Power Output by the Electrical Power Modifier Curve (function of temperature and elevation). If the result is greater than the numeric value specified in this input field, then the generator’s electrical power output is reset to the maximum full-load value specified in this input field. The value entered in this field must be greater than zero. If this field is left blank, then the value entered for the Reference Electrical Power Output field (above) will be used as the Maximum Full Load Electrical Power Output.

Field: Reference Electrical Efficiency (LHV Basis)

This numeric field contains the electrical efficiency of the generator at reference conditions, based on the lower heating value of the fuel. The electrical efficiency is the electric power output divided by the fuel energy consumption rate (LHV basis). The reference conditions are defined via additional input fields for this object (see below). This is a required input, and the value entered in this field must be greater than zero and less than or equal to 1.0.

Field: Reference Combustion Air Inlet Temperature

This numeric field specifies the reference temperature for the combustion inlet air in degrees celsius. If this field is left blank, the default value of 15°C will be used.

Field: Reference Combustion Air Inlet Humidity Ratio

This numeric field specifies the reference humidity ratio for the combustion inlet air in kg-H2O/kg-air. The value specified for this field must be greater than zero. If this field is left blank, the default value of 0.00638 kg-H2O/kg-air will be used.

Field: Reference Elevation

This numeric field specifies the reference elevation in meters (relative to sea level). The value specified for this field must be greater than or equal to -300.0 meters. If this field is left blank, the default value of 0.0 meters will be used.

Field: Electrical Power Modifier (function of temperature and elevation) Curve Name

This alpha field specifies the name of a bi-quadratic performance curve (ref: Performance Curves) that parameterizes the variation of electrical power output as a function of the combustion air inlet temperature and elevation. The output of this curve is multiplied by the Reference Electrical Power Output to give the full-load power output at a specific combustion air inlet temperature and elevation (i.e., at values different from the reference conditions). This curve should be normalized to have a value of 1.0 at the reference conditions, and the curve should be valid for the range of inlet air temperatures anticipated for the simulation period and for the actual elevation of the generator.

Field: Electrical Efficiency Modifier (function of temperature) Curve Name

This alpha field specifies the name of a quadratic or cubic performance curve (ref: Performance Curves) that parameterizes the variation of electrical efficiency as a function of the combustion air inlet temperature. The output of this curve is multiplied by the Reference Electrical Efficiency (LHV Basis) to give the full-load electrical efficiency at specific combustion air inlet temperatures (i.e., at inlet air temperatures different from the Reference Combustion Air Inlet Temperature). This curve should be normalized to have a value of 1.0 at the Reference Combustion Air Inlet Temperature, and the curve should be valid for the range of inlet air temperatures anticipated for the simulation period.

Field: Electrical Efficiency Modifier (function of part-load ratio) Curve Name

This alpha field specifies the name of a quadratic or cubic performance curve (ref: Performance Curves) that parameterizes the variation of electrical efficiency as a function of the generator's part-load ratio (part-load ratio is the actual electrical power output divided by the full-load electrical power output at the current operating conditions). The output of this curve is multiplied by the Reference Electrical Efficiency (LHV Basis) and the output of the Electrical Efficiency Modifier Curve (function of temperature) to give the electrical efficiency at specific part-load and combustion air inlet (temperature) conditions. This curve should be normalized to have a value of 1.0 when the generator's part-load ratio is 1.0, and the curve should be valid for the range of part-load ratios anticipated for the simulation period.

Field: Fuel Type

This choice field specifies the type of fuel used by the generator. If the field is left blank, the fuel type will be assumed to be NaturalGas.

Field: Fuel Higher Heating Value

This numeric field specifies the higher heating value of the fuel used in kJ/kg. The value specified for this field must be greater than zero and greater than the specified Fuel Lower Heating Value. If this field is left blank, the default value of 50,000 kJ/kg will be used.

Field: Fuel Lower Heating Value

This numeric field specifies the lower heating value of the fuel used in kJ/kg. The value specified for this field must be greater than zero but less than the specified Fuel Higher Heating Value. If this field is left blank, the default value of 45,450 kJ/kg will be used.

Field: Standby Power

This numeric field specifies the standby electric power consumed by the generator in Watts. The standby power is the electrical power consumed by the generator (e.g., air fans and controls) when the generator is available to operate but the generator electrical power output is zero (power output is not being requested by the electric load center). The value specified for this field must be greater than or equal to zero. If this field is left blank, the default value of 0.0 W will be used.

Field: Ancillary Power

This numeric field specifies the ancillary electric power consumed by the generator in Watts. The ancillary power is the electrical power consumed by other associated equipment (e.g., external fuel pressurization pumps) when the generator is operating. Specify this input as 0.0 if the Reference Electrical Power Output and Reference Electrical Efficiency (LHV Basis) input fields and associated modifier curves reflect the "net" electrical power output from the generator (i.e., ancillary power already deducted from the generator's gross electrical power output). A value greater than zero indicates that this electrical power is consumed whenever the generator is operating and will be deducted from the generator's overall electrical power output (Generator Electric Power Produced). The value specified for this field must be greater than or equal to zero. If this field is left blank, the default value of 0.0 W will be used.

Field: Ancillary Power Modifier (function of fuel input) Curve Name

This alpha field specifies the name of a quadratic performance curve (ref: Performance Curves) that parameterizes the variation of ancillary power as a function of the generator's input fuel mass flow rate (kg/s). The output of this curve is multiplied by the ancillary power to give the ancillary power at a specific fuel mass flow rate. If this field is left blank, the model assumes that the modifier curve is 1.0 for the entire simulation (i.e., the ancillary power is constant whenever the generator operates).

Field: Heat Recovery Water Inlet Node Name

This alpha field specifies the identifying name for the generator's heat recovery water inlet node.

Field: Heat Recovery Water Outlet Node Name

This alpha field specifies the identifying name for the generator's heat recovery water outlet node.

Field: Reference Thermal Efficiency (LHV Basis)

This numeric field specifies the thermal efficiency (heat recovery to water) at reference conditions, based on the lower heating value of the fuel. The thermal efficiency is the thermal power output (to water) divided by the fuel energy consumption rate (LHV basis). The reference conditions are defined via additional input fields for this object. This value must be from 0.0 to 1.0. If this field is left blank, the default value of 0.0 will be used.

Field: Reference Inlet Water Temperature

This numeric field specifies the reference temperature for the inlet water to the heat recovery heat exchanger in degrees Celsius.

Field: Heat Recovery Water Flow Operating Mode

This field is used to choose between different modes of controlling the mass flow rate of water being heated by energy recovered from exhaust air. There are two options available for this field: "Plant Control" or "Internal Control." The "Plant Control" option indicates that the heat recovery water flow rate through the generator is determined externally (by the wider balance of plant). In this case, the generator will request the Reference Heat Recovery Water Flow Rate whenever it operates but the actual flow rate may be limited by other plant components (e.g., pump). The "Internal Control" option indicates the flow of water is controlled inside the generator based on current operating conditions. For internal control, the generator should (probably) include a bypass branch when connecting to the plant loop.

__Field: Reference Heat Recovery Water Flow Rate__

This numeric field is the reference heat recovery (volumetric) water flow rate in cubic meters per second. Entered values must be greater than zero.

__Field: Heat Recovery Water Flow Rate Modifier (function of temperature and power) Curve Name__

This alpha field specifies the name of a bi-quadratic performance curve (ref: Performance Curves) that parameterizes the variation of heat recovery water flow rate as a function of the inlet water temperature and net electrical power output. This field is only used if the Heat Recovery Water Flow Operating Mode is 'Internal Control'. The output of this curve is multiplied by the Reference Heat Recovery Water Flow Rate to give the water flow rate at the specific inlet water temperature and net power operating conditions. This curve should be normalized to have a value of 1.0 at the reference conditions, and the curve should be valid for the range of inlet water temperatures and net electrical power output anticipated for the simulation period. If this field is left blank, the model assumes that the modifier curve is 1.0 for the entire simulation.

__Field: Thermal Efficiency Modifier (function of temperature and elevation) Curve Name__

This alpha field specifies the name of a bi-quadratic performance curve (ref: Performance Curves) that parameterizes the variation of thermal efficiency as a function of the combustion air inlet temperature and elevation. The output of this curve is multiplied by the Reference Thermal Efficiency to give the full-load thermal efficiency at a specific combustion air inlet temperature and elevation (i.e., at values different from the reference conditions). This curve should be normalized to have a value of 1.0 at the reference conditions, and the curve should be valid for the range of inlet air temperatures anticipated for the simulation period and for the actual elevation of the generator. If this field is left blank, the model assumes that the modifier curve is 1.0 for the entire simulation.

__Field: Heat Recovery Rate Modifier (function of part-load ratio) Curve Name__

This alpha field specifies the name of a quadratic or cubic performance curve (ref: Performance Curves) that parameterizes the variation of heat recovery to water (thermal power output) as a function of the generator's part-load ratio (part-load ratio is the actual electrical power output divided by the full-load electrical power output at the current operating conditions). The output of this curve is multiplied by the steady-state heat recovery at the current combustion inlet air temperature and elevation to give the heat recovery rate (thermal power output) at specific part-load operating conditions. This curve should be normalized to have a value of 1.0 when the generator's part-load ratio is 1.0, and the curve should be valid for the range of part-load ratios anticipated for the simulation period. If this field is left blank, the model assumes that the modifier curve is 1.0 for the entire simulation.

__Field: Heat Recovery Rate Modifier (function of inlet water temp) Curve Name__

This alpha field specifies the name of a quadratic performance curve (ref: Performance Curves) that parameterizes the variation of heat recovery to water (thermal power output) as a function of the inlet water temperature. The output of this curve is multiplied by the steady-state heat recovery at the current combustion inlet air temperature and elevation to give the heat recovery rate (thermal power output) at non-reference inlet water conditions. This curve should be normalized to have a value of 1.0 at the Reference Inlet Water Temperature, and the curve should be valid for the range of inlet water temperatures anticipated for the simulation period. If this field is left blank, the model assumes that the modifier curve is 1.0 for the entire simulation.

__Field: Heat Recovery Rate Modifier (function of water flow rate) Curve Name__

This alpha field specifies the name of a quadratic performance curve (ref: Performance Curves) that parameterizes the variation of heat recovery to water (thermal power output) as a function of the heat recovery water flow rate. The output of this curve is multiplied by the steady-state heat recovery at the current combustion inlet air temperature and elevation to give the heat recovery rate (thermal power output) at non-reference heat recovery water flow rates. This curve should be normalized to have a value of 1.0 at the Reference Heat

Recovery Water Flow Rate, and the curve should be valid for the range of water flow rates anticipated for the simulation period. If this field is left blank, the model assumes that the modifier curve is 1.0 for the entire simulation.

Field: Minimum Heat Recovery Water Flow Rate

This numeric field specifies the minimum (volumetric) water flow rate through the heat recovery heat exchanger in cubic meters per second. The minimum input value is 0.0, and a value of 0.0 is assumed if this field is left blank.

Field: Maximum Heat Recovery Water Flow Rate

This numeric field specifies the maximum (volumetric) water flow rate through the heat recovery heat exchanger in cubic meters per second. The minimum input value for this field is 0.0, and a value of 0.0 is assumed if this field is left blank. The maximum heat recovery water flow rate must be greater than or equal to the minimum heat recovery water flow rate.

Field: Maximum Heat Recovery Water Temperature

This field sets the maximum water temperature, in degrees Celsius, that this generator can produce via heat recovery. This temperature limit puts an upper bound on the recovered heat and limits the max temperatures leaving the component.

As temperatures in the water loop approach this maximum temperature, the temperature difference between the entering water and the surfaces in generator's heat recovery heat exchanger becomes smaller. For the given heat recovery flow rate and that temperature difference the amount of heat recovered will be reduced, and eventually there will be no heat recovered when the entering water temperature is equal to the maximum temperature specified by the user in this field. The amount of heat recovered will diminish if the inlet water temperature approaches the maximum temperature, and this will show up in the reporting.

Field: Combustion Air Inlet Node Name

This alpha field specifies the name of the combustion air inlet node. If a node name is specified, this node must be an outside air node and must also be specified elsewhere in the input (ref: Outside Air Node and Outside Air Inlet Node List). If this field is left blank, the combustion air inlet conditions are assumed to be the outdoor weather conditions used for the simulation.

Field: Combustion Air Outlet Node Name

This alpha field specifies the name of the combustion air outlet node.

Field: Reference Exhaust Air Mass Flow Rate

This numeric field is the reference exhaust air mass flow rate in kilograms per second. Entered values must be greater than zero.

Field: Exhaust Air Flow Rate Modifier (function of temperature) Curve Name

This alpha field specifies the name of a quadratic or cubic performance curve (ref: Performance Curves) that parameterizes the variation of exhaust air flow rate as a function of the combustion air inlet temperature. The output of this curve is multiplied by the Reference Exhaust Air Mass Flow Rate to give the exhaust air mass flow rate at non-reference combustion air inlet temperatures. This curve should be normalized to have a value of 1.0 at the Reference Combustion Air Inlet Temperature, and the curve should be valid for the range of inlet air temperatures anticipated for the simulation period. If this field is left blank, the model assumes that the modifier curve is 1.0 for the entire simulation.

Field: Exhaust Air Flow Rate Modifier (function of part-load ratio) Curve Name

This alpha field specifies the name of a quadratic or cubic performance curve (ref: Performance Curves) that parameterizes the variation of exhaust air flow rate as a function of the generator's part-load ratio (part-load ratio is the actual electrical power output divided by the full-load electrical power output at the current operating conditions). The output of this curve is multiplied by the Reference Exhaust Air Mass Flow Rate to give the exhaust air mass flow rate at specific part-load operating conditions. This curve should be normalized to have a value of 1.0 when the generator's part-load ratio is 1.0, and the curve should be valid for the range of part-load ratios anticipated for the simulation period. If this field is left blank, the model assumes that the modifier curve is 1.0 for the entire simulation.

Field: Nominal Exhaust Air Outlet Temperature

This numeric field is the exhaust air outlet temperature at nominal (reference) conditions in degrees Celsius.

Field: Exhaust Air Temperature Modifier (function of temperature) Curve Name

This alpha field specifies the name of a quadratic or cubic performance curve (ref: Performance Curves) that parameterizes the variation of exhaust air outlet temperature as a function of the combustion air inlet temperature. The output of this curve is multiplied by the Nominal Exhaust Air Outlet Temperature to give the exhaust air temperature at non-reference combustion air inlet temperatures. This curve should be normalized to have a value of 1.0 at the Reference Combustion Air Inlet Temperature, and the curve should be valid for the range of inlet air temperatures anticipated for the simulation period. If this field is left blank, the model assumes that the modifier curve is 1.0 for the entire simulation.

Field: Exhaust Air Temperature Modifier (function of part-load ratio) Curve Name

This alpha field specifies the name of a quadratic or cubic performance curve (ref: Performance Curves) that parameterizes the variation of exhaust air outlet temperature as a function of the generator's part-load ratio (part-load ratio is the actual electrical power output divided by the full-load electrical power output at the current operating conditions). The output of this curve is multiplied by the Nominal Exhaust Air Outlet Temperature to give the exhaust air temperature at specific part-load operating conditions. This curve should be normalized to have a value of 1.0 when the generator's part-load ratio is 1.0, and the curve should be valid for the range of part-load ratios anticipated for the simulation period. If this field is left blank, the model assumes that the modifier curve is 1.0 for the entire simulation.

```
GENERATOR:MICROTURBINE,
      \min-fields 11
  A1, \field Generator Name
      \required-field
      \type alpha
      \reference GeneratorNames
  N1, \field Reference Electrical Power Output
      \required-field
      \type real
      \units W
      \minimum> 0.0
  N2, \field Minimum Full Load Electrical Power Output
      \type real
      \units W
      \minimum 0.0
      \default 0.0
  N3, \field Maximum Full Load Electrical Power Output
      \type real
      \units W
      \minimum> 0.0
      \note If left blank, Maximum Full Load Electrical Power Output will be set
      \note equal to the Reference Electrical Power Output.
  N4, \field Reference Electrical Efficiency (LHV Basis)
      \required-field
      \type real
      \minimum> 0.0
      \maximum 1.0
      \note Electric power output divided by fuel energy input (LHV basis)
      \note at reference conditions.
  N5, \field Reference Combustion Air Inlet Temperature
      \type real
      \units C
      \default 15.0
  N6, \field Reference Combustion Air Inlet Humidity Ratio
      \type real
      \units kg-H2O/kg-air
      \minimum> 0.0
      \default 0.00638
  N7, \field Reference Elevation
      \type real
      \units m
      \minimum -300.0
      \default 0.0
  A2, \field Electrical Power Modifier (function of temperature and elevation) Curve Name
      \required-field
      \type object-list
      \object-list BiQuadraticCurves
      \note curve = a + b*T + c*T**2 + d*Elev + e*Elev**2 + f*T*Elev
      \note T = combustion air inlet temperature (C)
      \note Elev = elevation (m)
  A3, \field Electrical Efficiency Modifier (function of temperature) Curve Name
      \required-field
      \type object-list
      \object-list Quadratic_CubicCurves
      \note Quadratic curve = a + b*T + c*T**2
      \note Cubic curve = a + b*T + c*T**2 + d*T**3
      \note T = combustion air inlet temperature (C)
  A4, \field Electrical Efficiency Modifier (function of part-load ratio) Curve Name
      \required-field
      \type object-list
      \object-list Quadratic_CubicCurves
      \note Quadratic curve = a + b*PLR + c*PLR**2
      \note Cubic curve = a + b*PLR + c*PLR**2 + d*PLR**3
      \note PLR = ratio of Generator Load to Steady-State Electrical Power Output at
      \note current operating conditions
  A5, \field Fuel Type
      \type choice
      \key NaturalGas
      \key PropaneGas
      \default NaturalGas
  N8, \field Fuel Higher Heating Value
      \type real
      \units kJ/kg
      \default 50000
      \minimum> 0.0
```

```
  N9, \field Fuel Lower Heating Value
      \type real
      \units kJ/kg
      \default 45450
      \minimum> 0.0
 N10, \field Standby Power
      \type real
      \units W
      \default 0.0
      \minimum 0.0
      \note Electric power consumed when the generator is available but not being called
      \note by the Electric Load Center.
 N11, \field Ancillary Power
      \type real
      \units W
      \default 0.0
      \minimum 0.0
      \note Electric power consumed by ancillary equipment (e.g., external fuel pressurization pump).
      \note Set to zero if Reference Electrical Power Output is the ‘net’ value (ancillary power
      \note already deducted). Input value is positive, but indicates negative electric generation.
  A6, \field Ancillary Power Modifier (function of fuel input) Curve Name
      \type object-list
      \object-list QuadraticCurves
      \note Quadratic curve = a + b*mdot + c*mdot**2
      \note mdot = fuel mass flow rate (kg/s)
      \note If left blank, model assumes ancillary power defined in previous field is constant
      \note whenever the generator is operating.
  A7, \field Heat Recovery Water Inlet Node Name
      \type alpha
  A8, \field Heat Recovery Water Outlet Node Name
      \type alpha
 N12, \field Reference Thermal Efficiency (LHV Basis)
      \type real
      \minimum 0.0
      \maximum 1.0
      \default 0.0
      \note Reference thermal efficiency (heat recovery to water) based on the
      \note lower heating value (LHV) of the fuel.
 N13, \field Reference Inlet Water Temperature
      \type real
      \units C
  A9, \field Heat Recovery Water Flow Operating Mode
      \type choice
      \key Plant Control
      \key Internal Control
      \default Plant Control
      \note Plant control means the heat recovery water flow rate is determined by the plant,
      \note but the user needs to supply a heat recovery water flow rate.
      \note Internal control means the heat recovery water flow rate is controlled by this generator.
      \note If ‘Internal Control’ is selected, then the user needs to supply a reference heat
      \note recovery water flow rate and optionally the name of a heat recovery flow rate modifier curve.
 N14, \field Reference Heat Recovery Water Flow Rate
      \type real
      \units m3/s
      \minumum> 0.0
 A10, \field Heat Recovery Water Flow Rate Modifier (function of temperature and power) Curve Name
      \type object-list
      \object-list BiQuadraticCurves
      \note curve = a + b*T + c*T**2 + d*Pnet + e*Pnet + f*T*Pnet
      \note T = heat recovery inlet water temperature
      \note Pnet = net power output = electric power output - ancillary power
      \note If left blank, model assumes the heat recovery water flow rate is constant whenever the
      \note generator is operating, at the Reference HR Water Flow Rate defined in the previous field.
 A11, \field Thermal Efficiency Modifier (function of temperature and elevation) Curve Name
      \type object-list
      \object-list Bicubic_BiquadraticCurves
      \note Bicubic curve = a + b*T + c*T**2 + d*Elev + e*Elev**2 + f*T*Elev + g*T**3 + h*Elev**3 +
i*T**2*Elev + j*T*Elev**2
      \note Biquadratic curve = a + b*T + c*T**2 + d*Elev + e*Elev**2 + f*T*Elev
      \note T = combustion air inlet temperature (C)
      \note Elev = elevation (m)
      \note If field is left blank, model assumes this modifier equals 1 for entire simulation.
 A12, \field Heat Recovery Rate Modifier (function of part-load ratio) Curve Name
      \type object-list
      \object-list Quadratic_CubicCurves
```

```
     \note Quadratic curve = a + b*PLR + c*PLR**2
     \note Cubic curve = a + b*PLR + c*PLR**2 + d*PLR**3
     \note PLR = ratio of Generator Load to Steady-State Electrical Power Output at
     \note current operating conditions
     \note If field is left blank, model assumes this modifier equals 1 for entire simulation.
A13, \field Heat Recovery Rate Modifier (function of inlet water temp) Curve Name
     \type object-list
     \object-list QuadraticCurves
     \note Quadratic curve = a + b*T + c*T**2
     \note T = inlet water temperature (C)
     \note If field is left blank, model assumes this modifier equals 1 for entire simulation.
A14, \field Heat Recovery Rate Modifier (function of water flow rate) Curve Name
     \type object-list
     \object-list QuadraticCurves
     \note Quadratic curve = a + b*flow + c*flow**2
     \note flow = volumetric flow rate of water through the heat exchanger (m3/s)
     \note If field is left blank, model assumes this modifier equals 1 for entire simulation.
N15, \field Minimum Heat Recovery Water Flow Rate
     \type real
     \units m3/s
     \minimum 0.0
     \default 0.0
N16, \field Maximum Heat Recovery Water Flow Rate
     \type real
     \units m3/s
     \minimum 0.0
     \default 0.0
N17, \field Maximum Heat Recovery Water Temperature
     \type real
     \units C
A15, \field Combustion Air Inlet Node Name
     \type alpha
     \note Must be an outside air node.
A16, \field Combustion Air Outlet Node Name
     \type alpha
N18, \field Reference Exhaust Air Mass Flow Rate
     \type real
     \units kg/s
     \minimum> 0.0
A17, \field Exhaust Air Flow Rate Modifier (function of temperature) Curve Name
     \type object-list
     \object-list Quadratic_CubicCurves
     \note Quadratic curve = a + b*T + c*T**2
     \note Cubic curve = a + b*T + c*T**2 + d*T**3
     \note T = combustion air inlet temperature (C)
     \note If field is left blank, model assumes this modifier equals 1 for entire simulation.
A18, \field Exhaust Air Flow Rate Modifier (function of part-load ratio) Curve Name
     \type object-list
     \object-list Quadratic_CubicCurves
     \note Quadratic curve = a + b*PLR + c*PLR**2
     \note Cubic curve = a + b*PLR + c*PLR**2 + d*PLR**3
     \note PLR = ratio of Generator Load to Steady-State Electrical Power Output at
     \note current operating conditions.
     \note If field is left blank, model assumes this modifier equals 1 for entire simulation.
N19, \field Nominal Exhaust Air Outlet Temperature
     \type real
     \note Exhaust air outlet temperature at reference conditions.
A19, \field Exhaust Air Temperature Modifier (function of temperature) Curve Name
     \type object-list
     \object-list Quadratic_CubicCurves
     \note Quadratic curve = a + b*T + c*T**2
     \note Cubic curve = a + b*T + c*T**2 + d*T**3
     \note T = combustion air inlet temperature (C)
     \note If field is left blank, model assumes this modifier equals 1 for entire simulation.
A20; \field Exhaust Air Temperature Modifier (function of part-load ratio) Curve Name
     \type object-list
     \object-list Quadratic_CubicCurves
     \note Quadratic curve = a + b*PLR + c*PLR**2
     \note Cubic curve = a + b*PLR + c*PLR**2 + d*PLR**3
     \note PLR = ratio of Generator Load to Steady-State Electrical Power Output at
     \note current operating conditions.
     \note If field is left blank, model assumes this modifier equals 1 for entire simulation.
```

An example IDF showing how this object is used is provided below:

```
   GENERATOR:MICROTURBINE,
     Generator 3,                       !- Generator Name
     65000,                             !- Reference Electrical Power Output {W}
     29900,                             !- Minimum Full Load Electrical Power Output {W}
     65000,                             !- Maximum Full Load Electrical Power Output {W}
     0.29,                              !- Reference Electrical Efficiency (LHV Basis) {dimensionless}
     15.0,                              !- Reference Combustion Air Inlet Temperature {C}
     0.00638,                           !- Reference Combustion Air Inlet Humidity Ratio {kg-H2O/kg-air}
     0.0,                               !- Reference Elevation {m}
     Power_vs_Temp_Elev,  !- Electrical Power Modifier (function of temperature and elevation) Curve Name
     Efficiency_vs_Temp,  !- Electrical Efficiency Modifier (function of temperature) Curve Name
     Efficiency_vs_PLR,   !- Electrical Efficiency Modifier (function of part-load ratio) Curve Name
     NaturalGas,                        !- Fuel Type
     50000,                             !- Fuel Higher Heating Value {kJ/kg}
     45450,                             !- Fuel Lower Heating Value {kJ/kg}
     300,                               !- Standby Power {W}
     4500,                              !- Ancillary Power {W}
     ;                                  !- Ancillary Power Modifier (function of fuel input) Curve Name

!
! Electrical Power Modifier Curve (function of temperature and elevation)
! x = Dry-Bulb Temperature of Combustion Inlet Air (C) and y = Elevation (meters)
!
  CURVE:BIQUADRATIC,
    Power_vs_Temp_Elev,      !- Name
    1.2027697,               !- Coeff1 Constant
    -9.671305E-03,           !- Coeff2 x
    -4.860793E-06,           !- Coeff3 x**2
    -1.542394E-04,           !- Coeff4 y
    9.111418E-09,            !- Coeff5 y**2
    8.797885E-07,            !- Coeff6 x*y
    -17.8,                   !- minimum value of x
    50.0,                    !- maximum value of x
    0.0,                     !- minimum value of y
    3050.;                   !- maximum value of y
!
! Electrical Efficiency Modifier Curve (function of temperature)
! x = Dry-Bulb Temperature of Combustion Inlet Air (C)
!
  CURVE:CUBIC,
    Efficiency_vs_Temp,      !- Name
    1.0402217,               !- Coeff1 Constant
    -0.0017314,              !- Coeff2 x
    -6.497040E-05,           !- Coeff3 x**2
    5.133175E-07,            !- Coeff4 x**3
    -20.0,                   !- minimum value of x
    50.0;                    !- maximum value of x
!
! Electrical Efficiency Modifier Curve (function of part-load ratio)
! x = Part-Load Ratio (electrical load/steady-state electrical power output)
!
  CURVE:CUBIC,
    Efficiency_vs_PLR,       !- Name
    0.215290,                !- Coeff1 Constant
    2.561463,                !- Coeff2 x
    -3.24613,                !- Coeff3 x**2
    1.497306,                !- Coeff4 x**3
    0.03,                    !- minimum value of x
    1.0;                     !- maximum value of x

  ELECTRIC LOAD CENTER:DISTRIBUTION,
    Electric Load Center,    !- Load Center Name
    Backup Generators,       !- Generator List Name
    Demand Limit,            !- Generator Operation Scheme Type
    10000.0;                 !- Purchased Electrical Demand Limit for "Demand Limit" scheme {W}

  ELECTRIC LOAD CENTER:GENERATORS,
    Backup Generators,       !- Generator List Name
    Generator 1,             !- Generator #1 Name
    GENERATOR:IC Engine,     !- Generator #1 Type
    50000,                   !- Generator #1 Rated Electric Power Output
    ON PEAK GENERATOR SCHEDULE,   !- Generator #1 Availability Schedule
    Generator 2,             !- Generator #2 Name
    GENERATOR:COMBUSTION TURBINE, !- Generator #2 Type
    30000,                   !- Generator #2 Rated Electric Power Output
```

```
    OFF PEAK GENERATOR SCHEDULE,  !- Generator #2 Availability Schedule
    Generator 3,             !- Generator #3 Name
    GENERATOR:MICROTURBINE,  !- Generator #3 Type
    65000,                   !- Generator #3 Rated Electric Power Output
    MID PEAK GENERATOR SCHEDULE;  !- Generator #3 Availability Schedule
```

Generator:Microturbine Outputs

The output variables that are available for the Microturbine Generator are:

```
HVAC,Average,Generator Electric Power Produced [W]
HVAC,Sum,Generator Electric Energy Produced [J]
HVAC,Average,Generator Electric Efficiency LHV Basis [-]
HVAC,Average,Generator <Fuel Type> Consumption Rate HHV Basis [W]
HVAC,Average,Generator Fuel Consumption Rate HHV Basis [W]
HVAC,Sum,Generator <Fuel Type> Consumption HHV Basis [J]
HVAC,Sum,Generator Fuel Consumption HHV Basis [J]
HVAC,Average,Generator <Fuel Type> Mass Flow Rate [kg/s]

If Standby Power input field > 0.0:
HVAC,Average,Generator Standby Electric Power [W]
HVAC,Sum,Generator Standby Electric Consumption [J]

If Ancillary Power input field > 0.0:
HVAC,Average,Generator Ancillary Electric Power [W]
HVAC,Sum,Generator Ancillary Electric Consumption [J]

If heat recovery water inlet and outlet node names are entered (and valid):
HVAC,Average,Generator Thermal Power Produced [W]
HVAC,Sum,Generator Thermal Energy Produced [J]
HVAC,Average,Generator Thermal Efficiency LHV Basis [-]
HVAC,Average,Generator Heat Recovery Inlet Temperature [C]
HVAC,Average,Generator Heat Recovery Outlet Temperature [C]
HVAC,Average,Generator Heat Recovery Water Mass Flow Rate [kg/s]
```

Generator Electric Power Produced [W]

This output variable is the average electric power produced by the generator in Watts for the time step being reported. This is the “net” electric power produced, accounting for ancillary electric power consumed during generator operation.

Generator Electric Energy Produced [J]

This output variable is the electric energy produced by the generator in Joules for the time step being reported. This output is also added to a report meter with Resource Type = ElectricityProduced, End Use Key = Cogeneration, Group Key = Plant (Ref. Report Meter). This is the “net” electric energy produced, accounting for ancillary electric consumption during generator operation.

Generator Electric Efficiency LHV Basis [-]

This output variable is the average electric efficiency of the generator (lower heating value basis) for the time step being reported. The electric efficiency is the Generator Electric Power Produced in Watts divided by the generator’s fuel energy consumption rate in Watts (lower heating value basis).

Generator <FuelType> Consumption Rate HHV Basis [W]

This output variable is the average fuel-specific energy consumption rate of the electric generator in Watts (higher heating value basis) for the time step being reported. <FuelType> is the name of the fuel used by this electric generator. <FuelType> can be one of the following: Natural Gas (=> ‘Gas’) or Propane Gas (=>’Propane’).

Generator Fuel Consumption Rate HHV Basis [W]

This output variable is the average fuel energy consumption rate of the electric generator in Watts (higher heating value basis) for the time step being reported. The output variable name is non-fuel specific.

Generator <FuelType> Consumption HHV Basis [J]

This output variable is the fuel-specific energy consumption of the electric generator in Joules (higher heating value basis) for the time step being reported. This output is also added to a report meter with Resource Type = <FuelType>, End Use Key = Cogeneration, Group Key = Plant (Ref. Report Meter). <FuelType> is the name of the fuel used by this electric generator. <FuelType> can be one of the following: Natural Gas (=> 'Gas') or Propane Gas (=>'Propane').

Generator Fuel Consumption HHV Basis [J]

This output variable is the fuel energy consumption of the electric generator in Joules (higher heating value basis) for the time step being reported. The output variable name is non-fuel specific.

Generator <FuelType> Mass Flow Rate [kg/s]

This output variable is the average mass flow rate of fuel being consumed by the electric generator in kg/s for the time step being reported. <FuelType> is the name of the fuel used by this electric generator. <FuelType> can be one of the following: Natural Gas (=> 'Gas') or Propane Gas (=>'Propane').

Generator Standby Electric Power [W]

This output variable is the average standby electric power consumed by the generator in Watts for the time step being reported. Standby power is electrical power consumed by the generator (e.g., air fans and controls) when the generator is available to operate but the generator electrical power output is zero (power output is not being requested by the electric load center). This output variable is only produced when the user enters a value greater than 0.0 for the input field Standby Power.

Generator Standby Electric Consumption [J]

This output variable is the standby electric energy consumption for the generator in Joules for the time step being reported. This output is also added to a report meter with Resource Type = Electricity, End Use Key = Cogeneration, Group Key = Plant (Ref. Report Meter). This output variable is only produced when the user enters a value greater than 0.0 for the input field Standby Power.

Generator Ancillary Electric Power [W]

This output variable is the average ancillary electric power consumed by the generator in Watts for the time step being reported. Ancillary power is the electrical power consumed by other associated equipment (e.g., external fuel pressurization pumps) when the generator is operating. This output variable is only produced when the user enters a value greater than 0.0 for the input field Ancillary Power.

Generator Ancillary Electric Consumption [J]

This output variable is the ancillary electric energy consumption for the generator in Joules for the time step being reported. This energy consumption is already deducted from the output variable Generator Electric Energy Produced ("net" electric energy produced by the generator). This output variable is only produced when the user enters a value greater than 0.0 for the input field Ancillary Power.

Generator Thermal Power Produced [W]

This output variable is the average thermal power produced (i.e., exhaust energy recovery to heat water) in Watts for the time step being reported.

Generator Thermal Energy Produced [J]

This output variable is the thermal energy produced (i.e., exhaust energy recovery to heat water) in Joules for the time step being reported. This output is also added to a report meter with Resource Type = EnergyTransfer, End Use Key = HeatRecovery, Group Key = Plant (Ref. Report Meter).

Generator Thermal Efficiency LHV Basis [-]

This output variable is the average thermal efficiency of the generator (lower heating value basis) for the time step being reported. The thermal efficiency is the Generator Thermal Power Produced in Watts divided by the generator's fuel energy consumption rate in Watts (lower heating value basis).

Generator Heat Recovery Inlet Temperature [C]

This output variable is the average heat recovery inlet water temperature in degrees Celsius for the time step being reported.

Generator Heat Recovery Outlet Temperature [C]

This output variable is the average heat recovery outlet water temperature in degrees Celsius for the time step being reported.

Generator Heat Recovery Water Mass Flow Rate [kg/s]

This output variable is the average heat recovery water mass flow rate in kilograms per second for the time step being reported.

Engineering Document for Generator:Microturbine

Microturbine generators are small combustion turbines that produce electricity on a relatively small scale (e.g., 25kW to 500kW). This model uses nominal performance at reference conditions along with several modifier curves to determine electrical power output and fuel use at non-reference conditions. The modifier curve coefficients must be derived from manufacturers data. Standby and ancillary power can also be taken into account.

Exhaust air energy recovery for heating water can be also be modeled. Similar to electrical power output, thermal power (heat recovery to water) output is calculated using nominal performance at reference conditions with modifier curves to account for variations at non-reference conditions. The Electric Load Center:Generators and Electric Load Center:Distribution objects are used to define the availability and control of the electric generators included in the simulation (ref. Electric Load Center:Generators and Electric Load Center:Distribution).

For each simulation time step that the generator is being asked to operate (i.e., produce electrical power as determined by the Electric Load Center), the full load electrical output of the generator is determined using the user-defined reference electrical power output along with a bi-quadratic modifier curve to account for differences in the combustion air inlet temperature and elevation for the current simulation time step compared to the reference temperature and elevation (i.e., the modifier curve should evaluate to 1.0 at the reference combustion air inlet temperature and reference elevation).

$$P_{Elec,Full\,Load} = P_{Elec,Ref}\left(PowerFTempElev\right)$$

$$PowerFTempElev = a_1 + a_2\left(T_{a,i}\right) + a_3\left(T_{a,i}\right)^2 + a_4\left(Elev\right) + a_5\left(Elev\right)^2 + a_6\left(T_{a,i}\right)\left(Elev\right)$$

where:

$P_{Elec,Full\,Load}$ = Full load electrical power output (W)

$P_{Elec,Ref}$ = Reference Electrical Power Output, user input (W)

$PowerFTempElev$ = User-defined Electric Power Modifier Curve (function of temperature and elevation) evaluated at the current combustion air inlet temperature and elevation

$T_{a,i}$ = Combustion air inlet temperature (°C)

$Elev$ = Elevation (m). This value obtained from the LOCATION object or the weather file.

The full load electrical power output of the generator is then checked against the minimum and maximum full load electrical power outputs specified by the user:

$$P_{Elec,Full\,Load} = MIN\left(P_{Elec,Full\,Load}, P_{FL\_Max}\right)$$

$$P_{Elec,Full\,Load} = MAX\left(P_{Elec,Full\,Load}, P_{FL\_Min}\right)$$

P_{FL_Max} = Maximum Full Load Electrical Power Output, user input (W)

P_{FL_Min} = Minimum Full Load Electrical Power Output, user input (W)

The actual (operating) electrical power output from the generator is determined next based on the load requested by the Electric Load Center, the generator's minimum and maximum part-load ratios, and the ancillary power.

$$P_{Elec,Operating} = MAX\left(0.0,\left(Load + P_{Ancillary}\right)\right)$$

$$P_{Elec,Operating} = MIN\left(P_{Elec,Operating}, P_{Elec,Full\,Load}\right)$$

$$\begin{aligned}
&IF\ \left(P_{Elec,Full\,Load} > 0.0\right)\ THEN\\
&\quad PLR = {P_{Elec,Operating}}\big/{P_{Elec,Full\,Load}}\\
&\quad PLR = MIN\left(PLR, PLR_{\max}\right)\\
&\quad PLR = MAX\left(PLR, PLR_{\min}\right)\\
&ELSE\\
&\quad PLR = 0.0\\
&END\,IF\\
&P_{Elec,Operating} = P_{Elec,Full\,Load}\left(PLR\right)
\end{aligned}$$

where:

$P_{Elec,Operating}$ = Actual (operating) electrical power output (W)

$Load$ = Electrical power output being requested by the Electric Load Center (W)

$P_{Ancillary}$ = Ancillary Power, user input (W)

PLR = Part-load ratio of the electric generator

$PLR_{\max}$ = Maximum part-load ratio of the electric generator (i.e., the maximum value for the independent variable [PLR] defined in the Curve:Quadratic or Curve:Cubic object for the Electrical Efficiency Modifier Curve [function of part-load ratio])

$PLR_{\min}$ = Minimum part-load ratio of the electric generator (i.e., the minimum value for the independent variable [PLR] defined in the Curve:Quadratic or Curve:Cubic object for the Electrical Efficiency Modifier Curve [function of part-load ratio])

The generator's electrical efficiency is then calculated based on the user-specified reference electrical efficiency (lower heating value [LHV] basis) and two electrical efficiency modifier curves.

$$ElecEfficiencyFTemp = b_1 + b_2\left(T_{a,i}\right) + b_3\left(T_{a,i}\right)^2 \quad or \quad b_1 + b_2\left(T_{a,i}\right) + b_3\left(T_{a,i}\right)^2 + b_4\left(T_{a,i}\right)^3$$

$$ElecEfficiencyFPLR = c_1 + c_2\left(PLR\right) + c_3\left(PLR\right)^2 \quad or \quad c_1 + c_2\left(PLR\right) + c_3\left(PLR\right)^2 + c_4\left(PLR\right)^3$$

$$ElecEff_{Operating} = ElecEff_{Ref,LHV}\left(ElecEfficiencyFTemp\right)\left(ElecEfficiencyFPLR\right)$$

where:

$ElecEfficiencyFTemp$ = User-defined Electrical Efficiency Modifier Curve (function of temperature) evaluated at the current combustion air inlet temperature

$ElecEfficiencyFPLR$ = User-defined Electrical Efficiency Modifier Curve (function of part-load ratio) evaluated at the current operating part-load ratio

$ElecEff_{Operating}$ = Electrical efficiency at the current operating conditions

$ElecEff_{Ref,LHV}$ = Reference Electrical Efficiency (LHV [lower heating value] Basis), user input

The fuel energy consumption rate (LHV Basis) is then calculated as follows:

$$\dot{Q}_{Fuel,LHV} = P_{Elec,Operating} \Big/ ElecEff_{Operating}$$

where:

$\dot{Q}_{Fuel,LHV}$ = Fuel energy consumption rate, LHV basis (W)

If $ElecEff_{Operating}$ is equal to zero, then $P_{Operating}$ and $\dot{Q}_{Fuel,LHV}$ are set to zero. The fuel mass flow rate is then calculated.

$$\dot{m}_{fuel} = \dot{Q}_{Fuel,LHV} \Big/ \left(LHV * 1000\right)$$

where:

$\dot{m}_{fuel}$ = Mass flow rate of fuel being consumed by the generator (kg/s), report variable "Generator <FuelType> Mass Flow Rate [kg/s]"

LHV = Fuel Lower Heating Value, user input (kJ/kg)

The ancillary power is calculated next using the user-specified ancillary power and ancillary power modifier curve. The ancillary power modifier curve is a quadratic function with the generator's fuel mass flow rate as the independent variable. If an ancillary power modifier curve is not specified in the input file, the modifier is assumed to be 1.0 and the ancillary power will be constant throughout the simulation.

$$AnciPowFMdotFuel = d_1 + d_2\left(\dot{m}_{fuel}\right) + d_3\left(\dot{m}_{fuel}\right)^2$$

$$P_{Ancillary,Operating} = P_{Ancillary}\left(AnciPowFMdotFuel\right)$$

where:

$AnciPowFMdotFuel$ = User-defined Ancillary Power Modifier Curve (function of fuel input) evaluated at the actual fuel mass flow rate. This multiplier is assumed to be 1.0 if an ancillary power modifier curve name is not specified in the input.

$P_{Ancillary}$ = Ancillary power, user input (W)

$P_{Ancillary,Operating}$ = Ancillary electric power at the current fuel mass flow rate (W), report variable "Generator Ancillary Electric Power [W]".

If ancillary power is constant for the simulation (e.g., no modifier curve defined), then the calculations continue as described below. However, if an ancillary power modifier curve has been defined, then the calculations described above for $P_{ElecOperating}$, $ElecEff_{Operating}$, $\dot{Q}_{Fuel,LHV}$ and $P_{Ancillary,Operating}$ are recalculated in sequence until the solution converges.

The generator's "net" electrical power output is calculated as the difference between the generator's actual power output and the ancillary electric power as follows.

$$P_{Elec,Produced} = P_{Elec,Operating} - P_{Ancillary,Operating}$$

where:

$P_{Elec,Produced}$ = Generator net electric power output, report variable "Generator Electric Power Produced [W]"

The fuel energy consumption rate (higher heating value basis) for the generator is then calculated as follows:

$$\dot{Q}_{Fuel,HHV} = \dot{m}_{fuel}\left(HHV\right)\left(1000\right)$$

where:

$\dot{Q}_{Fuel,HHV}$ = fuel energy consumption rate (W), report variables "Generator <FuelType> Consumption Rate HHV Basis [W]" and "Generator Fuel Consumption Rate HHV Basis [W]"

HHV = Fuel Higher Heating Value, user input (kJ/kg)

Standby electrical power may also be modeled to simulate controls or other parasitics used by the generator. The standby power is calculated only when the generator is not operating (i.e., $Load$ from the Electric Load Center is zero). If the generator operates for a given timestep (i.e., $Load$ > 0.0), the standby power is set equal to 0.

$$
\begin{aligned}
&IF\ \left(Load <= 0.0\right)\ THEN \\
&\quad P_{Standby} = P_{Standby,user\,input} \\
&ELSE \\
&\quad P_{Standby} = 0.0 \\
&END\ IF
\end{aligned}
$$

where:

$P_{Standby,user\,input}$ = Standby power, user input (W)

$P_{Standby}$ = Report variable "Generator Standby Electric Power" (W)

Report variables for electric energy produced, electric efficiency (LHV basis), fuel consumption (HHV basis), standby electric consumption and ancillary electric consumption are calculated as follows:

$$E_{Elec,Produced} = P_{Elec,Produced}\left(TimeStepSys\right)\left(3600\right)$$

$$ElecEff_{Operating,LHV} = P_{Elec,Produced} \big/ \dot{Q}_{Fuel,LHV}$$

$$Q_{Fuel,HHV} = \dot{Q}_{Fuel,HHV}\left(TimeStepSys\right)\left(3600\right)$$

$$E_{Standby} = P_{Standby}\left(TimeStepSys\right)\left(3600\right)$$

$$E_{Ancillary} = P_{Ancillary,Operating}\left(TimeStepSys\right)\left(3600\right)$$

where:

$E_{Elec,Produced}$ = Report variable "Generator Electric Energy Produced [J]"

$ElecEff_{Operating,LHV}$ = Report variable "Generator Electric Efficiency LHV Basis [-]"

$Q_{Fuel,HHV}$ = Report variables "Generator <FuelType> Consumption HHV Basis [J]" and "Generator Fuel Consumption HHV Basis [J]"

$E_{Standby}$ = Report variable "Generator Standby Electric Consumption [J]"

$E_{Ancillary}$ = Report variable "Generator Ancillary Electric Consumption [J]"

$TimeStepSys$ = HVAC system simulation time step (hr)

In addition to calculating electric power production and fuel usage, the model is able to determine thermal power (heat recovery) output for heating water. For this case, the water flow rate through the heat recovery heat exchanger is established first. If the Heat Recovery Water Flow Operating Mode (user input) is set to Plant Control, then the Reference Heat Recovery Water Flow Rate (user input) is requested whenever the generator operates (constant value), but the actual flow rate may be restricted by other plant components (e.g., pump). If the Heat Recovery Water Flow Operating Mode is set to Internal Control, then the requested water flow when the generator operates is determined by the Reference Heat Recovery Water Flow Rate and a flow rate modifier curve.

$$
\begin{aligned}
&IF\ \left(Plant\,Control\right)\ THEN\\
&\quad \dot{m}_w = \dot{V}_{w,Ref}\left(\rho_w\right)\\
&ELSEIF\left(Internal\,Control\right)THEN\\
&\quad HeatRecFlowFTempPow = e_1 + e_2\left(T_{w,i}\right) + e_3\left(T_{w,i}\right)^2 + e_4\left(P_{net}\right) + e_5\left(P_{net}\right)^2 + e_6\left(T_{w,i}\right)\left(P_{net}\right)\\
&\quad \dot{m}_w = \dot{V}_{w,Ref}\left(\rho_w\right)\left(HeatRecFlowFTempPow\right)\\
&END\,IF
\end{aligned}
$$

where:

$\dot{m}_w$ = Report variable "Generator Heat Recovery Water Mass Flow Rate [kg/s]"

$\dot{V}_{w,Ref}$ = Reference Heat Recovery Water Flow Rate (m^3/s), user input

ρ_w = Density of water (kg/m^3) at 5.05°C

$HeatRecFlowFTempPow$ = User-defined Heat Recovery Water Flow Rate Modifier Curve (function of temperature and power) evaluated at the current inlet water temperature and net electrical power output. This multiplier is assumed to be 1.0 if a water flow rate modifier curve name is not specified in the input.

$T_{w,i}$ = Heat recovery inlet water temperature (°C), report variable "Generator Heat Recovery Inlet Temperature [C]"

P_{net} = Net electrical power output from the generator (W)

The methodology for determining thermal power (heat recovery to water) is similar to that used for calculating electric power production. The generator's steady-state thermal efficiency is calculated based on the user-specified reference thermal efficiency (LHV basis) and a thermal efficiency modifier curve.

$$ThermalEff_{SS} = ThermalEff_{Ref,LHV}\left(ThermalEffFTempElev\right)$$

$$ThermalEffFTempElev = f_1 + f_2\left(T_{a,i}\right) + f_3\left(T_{a,i}\right)^2 + f_4\left(Elev\right) + f_5\left(Elev\right)^2 + f_6\left(T_{a,i}\right)\left(Elev\right)$$

where:

$ThermalEff_{SS}$ = Steady-state thermal efficiency at current conditions

$ThermalEff_{Ref,LHV}$ = Reference Thermal Efficiency (LHV Basis), user input

$ThermalEffFTempElev$ = User-defined Thermal Efficiency Modifier Curve (function of temperature and elevation) evaluated at the current combustion air inlet temperature and elevation. This multiplier is assumed to be 1.0 if a thermal efficiency modifier curve name is not specified in the input.

The steady-state thermal power produced (heat recovery rate) is then calculated:

$$P_{Thermal,SS} = ThermalEff_{SS}\left(\dot{Q}_{Fuel,LHV}\right)$$

The actual (operating) thermal power is then calculated using the steady-state thermal power and three modifier curves:

$$P_{Thermal,Operating} = P_{Thermal,SS}\left(HeatRecRateFPLR\right)\left(HeatRecRateFTemp\right)\left(HeatRecRateFFlow\right)$$

$$HeatRecRateFPLR = g_1 + g_2\left(PLR\right) + g_3\left(PLR\right)^2 \quad -or- \quad g_1 + g_2\left(PLR\right) + g_3\left(PLR\right)^2 + g_4\left(PLR\right)^3$$

$$HeatRecRateFTemp = h_1 + h_2\left(T_{w,i}\right) + h_3\left(T_{w,i}\right)^2$$

$$HeatRecRateFFlow = i_1 + i_2\left(\dot{m}_w\right) + i_3\left(\dot{m}_w\right)^2$$

where:

$P_{Thermal,Operating}$ = Report variable “Generator Thermal Power Produced [W]”

$HeatRecRateFPLR$ = User-defined Heat Recovery Rate Modifier Curve (function of part-load ratio) evaluated at the current operating part-load ratio. This multiplier is assumed to be 1.0 if a modifier curve name is not specified in the input.

$HeatRecRateFTemp$ = User-defined Heat Recovery Rate Modifier Curve (function of inlet water temperature) evaluated at the current inlet water temperature. This multiplier is assumed to be 1.0 if a modifier curve name is not specified in the input.

$HeatRecRateFFlow$ = User-defined Heat Recovery Rate Modifier Curve (function of water flow rate) evaluated at the current heat recovery water flow rate. This multiplier is assumed to be 1.0 if a modifier curve name is not specified in the input.

The heat recovery output water temperature is then calculated.

$$T_{w,o} = T_{w,i} + P_{Thermal,Operating} \Big/ \left(\dot{m}_w * Cp_w\right)$$

where:

$T_{w,o}$ = Heat recovery outlet water temperature (°C), report variable "Generator Heat Recovery Outlet Temperature [C]"

Cp_w = Heat capacity of water (J/kg-K)

If the calculated heat recovery outlet water temperature exceeds to Maximum Heat Recovery Water Temperature (user input), then the outlet water temperature is reset to the maximum temperature (user input) and the thermal power is recalculated.

If combustion air inlet and outlet node names are specified in the input, along with exhaust air flow rate and exhaust air temperature information, then the model calculates the exhaust air conditions for each simulation time step. The exhaust air mass flow rate is first calculated based on the Reference Exhaust Air Mass Flow Rate, two modifier curves and an air density adjustment. Since fans are volumetric flow devices, the ratio of the air density at actual inlet air conditions to air density at reference inlet air conditions is used as an adjustment factor.

$$\dot{m}_{ExhAir} = \dot{m}_{ExhAir,Ref}\left(ExhFlowFTemp\right)\left(ExhFlowFPLR\right)\left(\rho_{a,i} \Big/ \rho_{a,Ref}\right)$$

$$ExhFlowFTemp = j_1 + j_2\left(T_{a,i}\right) + j_3\left(T_{a,i}\right)^2 \quad -or-$$

$$j_1 + j_2\left(T_{a,i}\right) + j_3\left(T_{a,i}\right)^2 + j_4\left(T_{a,i}\right)^3$$

$$ExhFlowFPLR = k_1 + k_2\left(PLR\right) + k_3\left(PLR\right)^2 \quad -or-$$

$$k_1 + k_2\left(PLR\right) + k_3\left(PLR\right)^2 + k_4\left(PLR\right)^3$$

where:

$\dot{m}_{ExhAir}$ = Exhaust air mass flow rate (kg/s)

$\dot{m}_{ExhAir,Ref}$ = Reference Exhaust Air Mass Flow Rate (kg/s), user input

$ExhFlowFTemp$ = User-defined Exhaust Air Flow Rate Modifier Curve (function of temperature) evaluated at the current combustion air inlet temperature. This multiplier is assumed to be 1.0 if a modifier curve name is not specified in the input.

$ExhFlowFPLR$ = User-defined Exhaust Air Flow Rate Rate Modifier Curve (function of part-load ratio) evaluated at the current operating part-load ratio. This multiplier is assumed to be 1.0 if a modifier curve name is not specified in the input.

$\rho_{a,i}$ = Density of the combustion inlet air (kg/m^3)

$\rho_{a,Ref}$ = Density of combustion inlet air at reference conditions (kg/m^3)

In an analogous fashion, the exhaust air temperature is calculated using the Nominal (reference) Exhaust Air Outlet Temperature and two modifier curves.

$$T_{a,o} = T_{a,o,Nom}\left(ExhAirTempFTemp\right)\left(ExhAirTempFPLR\right)$$

$$ExhAirTempFTemp = l_1 + l_2\left(T_{a,i}\right) + l_3\left(T_{a,i}\right)^2 \quad -or-$$

$$l_1 + l_2\left(T_{a,i}\right) + l_3\left(T_{a,i}\right)^2 + l_4\left(T_{a,i}\right)^3$$

$$ExhAirTempFPLR = m_1 + m_2\left(PLR\right) + m_3\left(PLR\right)^2 \quad -or-$$

$$m_1 + m_2\left(PLR\right) + m_3\left(PLR\right)^2 + m_4\left(PLR\right)^3$$

where:

$T_{a,o}$ = Exhaust air outlet temperature (°C)

$T_{a,o,Nom}$ = Nominal Exhaust Air Outlet Temperature (°C), user input

$ExhAirTempFTemp$ = User-defined Exhaust Air Temperature Modifier Curve (function of temperature) evaluated at the current combustion air inlet temperature. This multiplier is assumed to be 1.0 if a modifier curve name is not specified in the input.

$ExhAirTempFPLR$ = User-defined Exhaust Air Flow Rate Rate Modifier Curve (function of part-load ratio) evaluated at the current operating part-load ratio. This multiplier is assumed to be 1.0 if a modifier curve name is not specified in the input.

The above calculations for exhaust air outlet temperature assume no heat recovery to water is being done. If thermal power (water heating) is being produced, then the exhaust air outlet temperature is recalculated as follows:

$$T_{a,o} = T_{a,o} - P_{Thermal,Operating} \Big/ \left(\dot{m}_{ExhAir} * Cp_{air}\right)$$

where:

Cp_{air} = Heat capacity of air at the actual combustion air inlet conditions (J/kg-K)

The exhaust air outlet humidity ratio is also calculated.

$$w_{a,o} = w_{a,i} + \left[\dot{m}_{fuel}\left(HHV - LHV\right)\left(1000\right) \Big/ \left(h_{fg,16}\right)\right] \Big/ \left(\dot{m}_{ExhAir}\right)$$

where:

$w_{a,o}$ = Exhaust air outlet humidity ratio (kg/kg)

$w_{a,i}$ = Exhaust air inlet humidity ratio (kg/kg)

$h_{fg,16}$ = Enthalpy of vaporization of moisture at 16°C (J/kg)

The remaining report variables are calculated as follows.

$$E_{Thermal,Produced} = P_{Thermal,Operating}\left(TimeStepSys\right)\left(3600\right)$$

$$ThermalEff_{Operating,LHV} = {P_{Thermal,Operating}}\Big/{\dot{Q}_{Fuel,LHV}}$$

where:

$E_{Thermal,Produced}$ = Report variable "Generator Thermal Energy Produced [J]"

$ThermalEff_{Operating,LHV}$ = Report variable "Generator Thermal Efficiency LHV Basis [-]"

Reference Input Data Set for Generator:Microturbine

```
!=====================================================================================
! ElectricGenerators.idf
!
! This dataset includes inputs for the GENERATOR:MICROTURBINE object and
! associated performance curves. The performance curves were developed from
! manufacturers data collected in Summer 2007.
!
!                      Reference Electric   Reference Electrical
! Generator Name       Power Output (kW)    Efficiency (LHV basis)
!-------------------------------------------------------------------
! Capstone C65                 65                 0.29
! Elliott TA100               100                 0.2874
! Ingersoll Rand MT70          70                 0.28
! Ingersoll Rand MT250        250                 0.29

!
! Capstone C65
! References:
!  Capstone Doc #480014 Rev A (Feb 2006)
!  Capstone Doc #410048 Rev A (Dec 2005)
!  Capstone Doc #460000-001 Rev H (Dec 2005)
!  http://www.microturbine.com/
!  Data accounts for external gas pressure booster pump (ancillary power)
!
 GENERATOR:MICROTURBINE,
   Capstone C65,                   !- Generator Name
   65000,                          !- Reference Electrical Power Output {W}
   29900,                          !- Minimum Full Load Electrical Power Output {W}
   65000,                          !- Maximum Full Load Electrical Power Output {W}
   0.29,                           !- Reference Electrical Efficiency (LHV basis)
                                      {dimensionless}
   15.0,                           !- Reference Combustion Air Inlet Temperature {C}
   0.00638,                        !- Reference Combustion Air Inlet Humidity Ratio {kg-
                                      H2O/kg-air}
   0.0,                            !- Reference Elevation {m}
   Capstone C65 Power_vs_Temp_Elev, !- Electrical Power Modifier (function of temperature
                                      and elevation) Curve Name
   Capstone C65 Efficiency_vs_Temp, !- Electrical Efficiency Modifier (function of
                                      temperature) Curve Name
   Capstone C65 Efficiency_vs_PLR,  !- Electrical Efficiency Modifier (function of part-
                                      load ratio) Curve Name
   NaturalGas,                     !- Fuel Type
   50000,                          !- Fuel Higher Heating Value {kJ/kg}
   45450,                          !- Fuel Lower Heating Value {kJ/kg}
   300,                            !- Standby Power {W}
   4500,                           !- Ancillary Power {W}
   ;                               !- Ancillary Power Modifier (function of fuel input)
                                      Curve Name
```

```
!
! Curve set (3 Curves):
!
! Electrical Power Modifier Curve (function of temperature and elevation)
! x = Dry-Bulb Temperature of Combustion Inlet Air (C) and y = Elevation (meters)
!
 CURVE:BIQUADRATIC,
   Capstone C65 Power_vs_Temp_Elev, !- Name
   1.2027697,        !- Coeff1 Constant
   -9.671305E-03,    !- Coeff2 x
   -4.860793E-06,    !- Coeff3 x**2
   -1.542394E-04,    !- Coeff4 y
   9.111418E-09,     !- Coeff5 y**2
   8.797885E-07,     !- Coeff6 x*y
   -17.8,            !- minimum value of x
   50.0,             !- maximum value of x
   0.0,              !- minimum value of y
   3050.;            !- maximum value of y
!
! Electrical Efficiency Modifier Curve (function of temperature)
! x = Dry-Bulb Temperature of Combustion Inlet Air (C)
!
 CURVE:CUBIC,
   Capstone C65 Efficiency_vs_Temp,  !- Name
   1.0402217,        !- Coeff1 Constant
   -0.0017314,       !- Coeff2 x
   -6.497040E-05,    !- Coeff3 x**2
   5.133175E-07,     !- Coeff4 x**3
   -20.0,            !- minimum value of x
   50.0;             !- maximum value of x
!
! Electrical Efficiency Modifier Curve (function of part-load ratio)
! x = Part-Load Ratio (electrical load/full load electrical power output)
!
 CURVE:CUBIC,
   Capstone C65 Efficiency_vs_PLR,  !- Name
   0.215290,         !- Coeff1 Constant
   2.561463,         !- Coeff2 x
   -3.24613,         !- Coeff3 x**2
   1.497306,         !- Coeff4 x**3
   0.03,             !- minimum value of x
   1.0;              !- maximum value of x


!
! Elliott TA100
! References:
!  Direct correspondence with manufacturer personnel.
!  http://www.elliottmicroturbines.com
!  Data accounts for integrated gas pressure booster pump
!
 GENERATOR:MICROTURBINE,
   Elliott TA100,                    !- Generator Name
   100000,                           !- Reference Electrical Power Output {W}
   40000,                            !- Minimum Full Load Electrical Power Output {W}
   100000,                           !- Maximum Full Load Electrical Power Output {W}
   0.2874,                           !- Reference Electrical Efficiency (LHV basis)
                                        {dimensionless}
   15.0,                             !- Reference Combustion Air Inlet Temperature {C}
   0.00638,                          !- Reference Combustion Air Inlet Humidity Ratio {kg-
                                        H2O/kg-air}
   0.0,                              !- Reference Elevation {m}
   Elliott TA100 Power_vs_Temp_Elev, !- Electrical Power Modifier (function of temperature
                                        and elevation) Curve Name
   Elliott TA100 Efficiency_vs_Temp, !- Electrical Efficiency Modifier (function of
                                        temperature) Curve Name
   Elliott TA100 Efficiency_vs_PLR,  !- Electrical Efficiency Modifier (function of part-
                                        load ratio) Curve Name
   NaturalGas,                       !- Fuel Type
   50000,                            !- Fuel Higher Heating Value {kJ/kg}
   45450,                            !- Fuel Lower Heating Value {kJ/kg}
```

```
    300,                                !- Standby Power {W}
    0,                                  !- Ancillary Power {W}
    ;                                   !- Ancillary Power Modifier (function of fuel input)
                                           Curve Name
!
! Curve set (3 Curves):
!
! Electrical Power Modifier Curve (function of temperature and elevation)
! x = Dry-Bulb Temperature of Combustion Inlet Air (C) and y = Elevation (meters)
!
 CURVE:BIQUADRATIC,
   Elliott TA100 Power_vs_Temp_Elev, !- Name
   1.23063,          !- Coeff1 Constant
   -0.01258,         !- Coeff2 x
   0.0,              !- Coeff3 x**2
!  Elevation data not available from manufacturer.
!  Assuming linear reduction of 3.4% per 1000 ft (305 m) elevation
!  per Microturbine Technology Characterization for the US Environmental
!  Protection Agency, Energy Nexus Group, March 2002
   -1.11475E-04,     !- Coeff4 y
   0.0,              !- Coeff5 y**2
   0.0,              !- Coeff6 x*y
   -7.0,             !- minimum value of x
   50.0,             !- maximum value of x
   0.0,              !- minimum value of y
   3050.;            !- maximum value of y
!
! Electrical Efficiency Modifier Curve (function of temperature)
! x = Dry-Bulb Temperature of Combustion Inlet Air (C)
!
 CURVE:CUBIC,
   Elliott TA100 Efficiency_vs_Temp,  !- Name
   1.0021679,        !- Coeff1 Constant
   8.89497E-04,      !- Coeff2 x
   -7.06607E-05,     !- Coeff3 x**2
   -6.98114E-07,     !- Coeff4 x**3
   -7.0,             !- minimum value of x
   50.0;             !- maximum value of x
!
! Electrical Efficiency Modifier Curve (function of part-load ratio)
! x = Part-Load Ratio (electrical load/full load electrical power output)
!
 CURVE:CUBIC,
   Elliott TA100 Efficiency_vs_PLR,  !- Name
   -1.0547119E-15,  !- Coeff1 Constant
   1.91926871211,   !- Coeff2 x
   -1.14135760342,  !- Coeff3 x**2
   0.222088891305,  !- Coeff4 x**3
   0.0001,          !- minimum value of x
   1.0;             !- maximum value of x



!
! Ingersoll Rand MT70
! References:
!  Website materials (June 2007) and direct correspondence with manufacturer personnel.
!  http://energy.ingersollrand.com
!  Data accounts for integrated gas pressure booster pump
!
 GENERATOR:MICROTURBINE,
   Ingersoll Rand MT70,                !- Generator Name
   70000,                              !- Reference Electrical Power Output {W}
   32591,                              !- Minimum Full Load Electrical Power Output {W}
   90000,                              !- Maximum Full Load Electrical Power Output {W}
   0.28,                               !- Reference Electrical Efficiency (LHV basis)
                                          {dimensionless}
   15.0,                               !- Reference Combustion Air Inlet Temperature {C}
   0.00638,                            !- Reference Combustion Air Inlet Humidity Ratio {kg-
                                          H2O/kg-air}
   0.0,                                !- Reference Elevation {m}
   Ingersoll Rand MT70 Power_vs_Temp_Elev, !- Electrical Power Modifier (function of
```

```
                                                 temperature and elevation) Curve Name
  Ingersoll Rand MT70 Efficiency_vs_Temp, !- Electrical Efficiency Modifier (function of
                                                 temperature) Curve Name
  Ingersoll Rand MT70 Efficiency_vs_PLR,  !- Electrical Efficiency Modifier (function of
                                                 part-load ratio) Curve Name
  NaturalGas,                        !- Fuel Type
  50000,                             !- Fuel Higher Heating Value {kJ/kg}
  45450,                             !- Fuel Lower Heating Value {kJ/kg}
  500,                               !- Standby Power {W}
  0,                                 !- Ancillary Power {W}
  ;                                  !- Ancillary Power Modifier (function of fuel input)
                                        Curve Name
!
! Curve set (3 Curves):
!
! Electrical Power Modifier Curve (function of temperature and elevation)
! x = Dry-Bulb Temperature of Combustion Inlet Air (C) and y = Elevation (meters)
!
 CURVE:BIQUADRATIC,
  Ingersoll Rand MT70 Power_vs_Temp_Elev, !- Name
  1.1100093,          !- Coeff1 Constant
  -8.959532E-03,      !- Coeff2 x
  1.433197E-05,       !- Coeff3 x**2
!  Linear reduction of 3.5% per 1000 ft (305 m) elevation
  -1.14754E-04,       !- Coeff4 y
  0.0,                !- Coeff5 y**2
  0.0,                !- Coeff6 x*y
  -17.8,              !- minimum value of x
  46.1,               !- maximum value of x
  0.0,                !- minimum value of y
  3050.;              !- maximum value of y
!
! Electrical Efficiency Modifier Curve (function of temperature)
! x = Dry-Bulb Temperature of Combustion Inlet Air (C)
!
 CURVE:QUADRATIC,
  Ingersoll Rand MT70 Efficiency_vs_Temp,  !- Name
  1.0260503,       !- Coeff1 Constant
  -1.68174E-03,    !- Coeff2 x
  -1.11640E-05,    !- Coeff3 x**2
  -17.8,           !- minimum value of x
  46.1;            !- maximum value of x
!
! Electrical Efficiency Modifier Curve (function of part-load ratio)
! x = Part-Load Ratio (electrical load/full load electrical power output)
!
 CURVE:CUBIC,
  Ingersoll Rand MT70 Efficiency_vs_PLR,  !- Name
  0.0,             !- Coeff1 Constant
  2.96440584,      !- Coeff2 x
  -3.157155,       !- Coeff3 x**2
  1.19274913,      !- Coeff4 x**3
  0.5,             !- minimum value of x
  1.0;             !- maximum value of x


!
! Ingersoll Rand MT250
! References:
!  Website materials (June 2007) and direct correspondence with manufacturer personnel.
!  http://energy.ingersollrand.com
!  Data accounts for integrated gas pressure booster pump
!
 GENERATOR:MICROTURBINE,
  Ingersoll Rand MT250,               !- Generator Name
  250000,                             !- Reference Electrical Power Output {W}
  110000,                             !- Minimum Full Load Electrical Power Output {W}
  300000,                             !- Maximum Full Load Electrical Power Output {W}
  0.29,                               !- Reference Electrical Efficiency (LHV basis)
                                         {dimensionless}
  15.0,                               !- Reference Combustion Air Inlet Temperature {C}
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   0.00638,                            !- Reference Combustion Air Inlet Humidity Ratio {kg-
                                          H2O/kg-air}
   0.0,                                !- Reference Elevation {m}
   Ingersoll Rand MT250 Power_vs_Temp_Elev, !- Electrical Power Modifier (function of
                                                temperature and elevation) Curve Name
   Ingersoll Rand MT250 Efficiency_vs_Temp, !- Electrical Efficiency Modifier (function of
                                                temperature) Curve Name
   Ingersoll Rand MT250 Efficiency_vs_PLR,  !- Electrical Efficiency Modifier (function of
                                                part-load ratio) Curve Name
   NaturalGas,                         !- Fuel Type
   50000,                              !- Fuel Higher Heating Value {kJ/kg}
   45450,                              !- Fuel Lower Heating Value {kJ/kg}
   1500,                               !- Standby Power {W}
   0,                                  !- Ancillary Power {W}
   ;                                   !- Ancillary Power Modifier (function of fuel input)
                                          Curve Name
!
! Curve set (3 Curves):
!
! Electrical Power Modifier Curve (function of temperature and elevation)
! x = Dry-Bulb Temperature of Combustion Inlet Air (C) and y = Elevation (meters)
!
 CURVE:BIQUADRATIC,
   Ingersoll Rand MT250 Power_vs_Temp_Elev, !- Name
   1.073797,         !- Coeff1 Constant
   -6.74610E-03,     !- Coeff2 x
   -4.12856E-05,     !- Coeff3 x**2
!  Linear reduction of 3.5% per 1000 ft (305 m) elevation
   -1.14754E-04,     !- Coeff4 y
   0.0,              !- Coeff5 y**2
   0.0,              !- Coeff6 x*y
   -17.8,            !- minimum value of x
   46.1,             !- maximum value of x
   0.0,              !- minimum value of y
   3050.;            !- maximum value of y
!
! Electrical Efficiency Modifier Curve (function of temperature)
! x = Dry-Bulb Temperature of Combustion Inlet Air (C)
!
 CURVE:CUBIC,
   Ingersoll Rand MT250 Efficiency_vs_Temp,  !- Name
   1.045428,       !- Coeff1 Constant
   -1.98019E-03,   !- Coeff2 x
   -7.65274E-05,   !- Coeff3 x**2
   7.31154E-07,    !- Coeff4 x**3
   -17.8,          !- minimum value of x
   46.1;           !- maximum value of x
!
! Electrical Efficiency Modifier Curve (function of part-load ratio)
! x = Part-Load Ratio (electrical load/full load electrical power output)
!
 CURVE:CUBIC,
   Ingersoll Rand MT250 Efficiency_vs_PLR,  !- Name
   0.0,         !- Coeff1 Constant
   0.884774,    !- Coeff2 x
   1.023073,    !- Coeff3 x**2
   -0.907847,   !- Coeff4 x**3
   0.5,         !- minimum value of x
   1.0;         !- maximum value of x
```